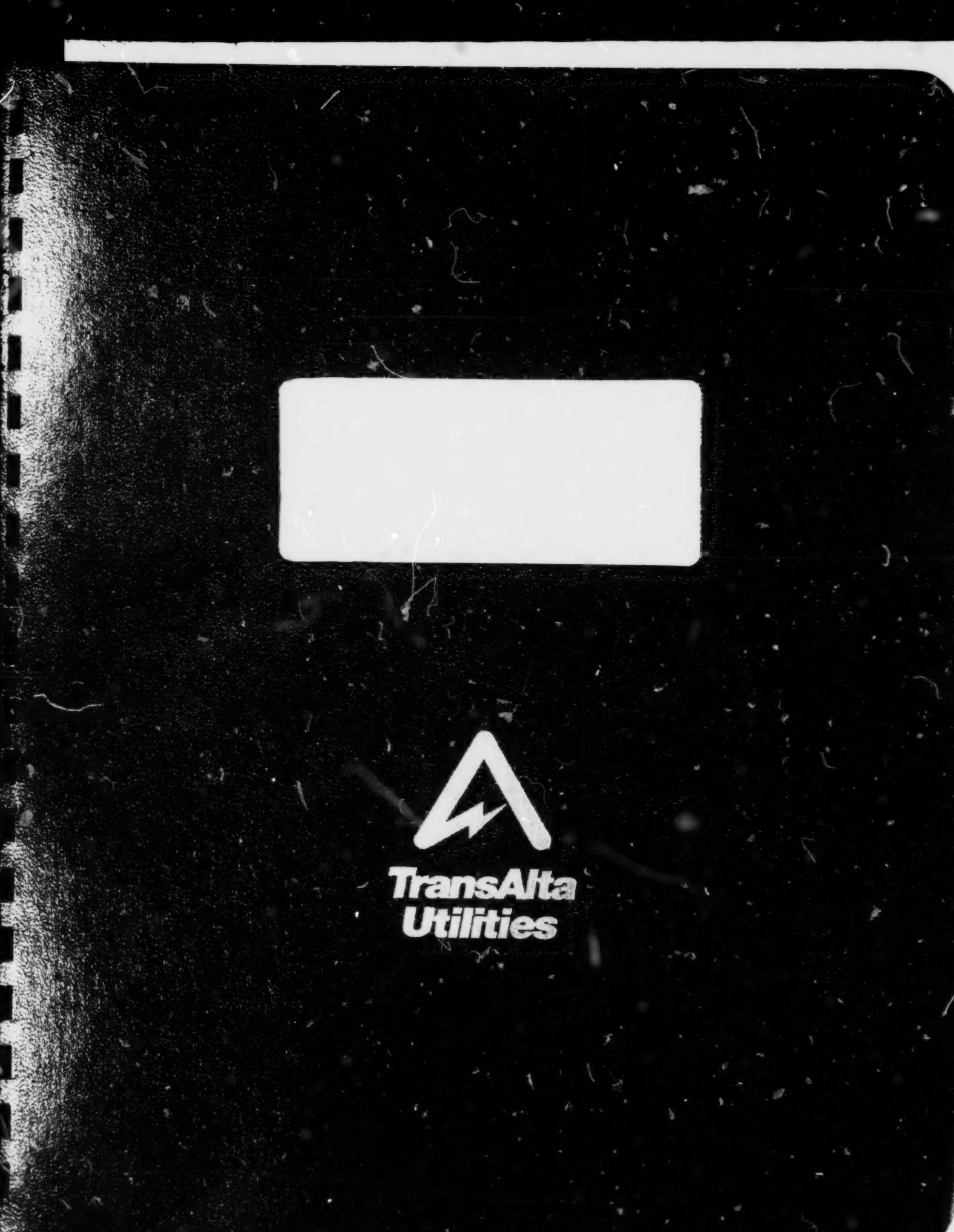
TransAlta
Utilities

HIGH TEMPERATURE, HIGH PRESSURE GAS STREAM CLEANUP:

A REVIEW OF THE STATE OF THE ART

FINAL REPORT

Submitted by

TransAlta Utilities Corporation

Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada

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Attention: Dr. E. Furimsky
Heat, Pyrolysis and Gasification Section
CCRL

Dear Dr. Furimsky:

Subject: Hot Gas Cleanup Research

We are pleased to submit 10 copies of our final report on the Hot Gas Cleanup Research. This report contains material which is an extension to the work carried out for our earlier report on Gasification of Western Canadian Coal, prepared for the Alberta Office of Coal Research and Technology in January of this year.

In view of recent developments in coal gasification and in the application of this technology to power generation, we believe this to be a timely review of the current state-of-the-art.

The report reviews recent research carried out on methods of removing pollutants from coal derived gas streams at high temperature and pressure. It also reviews current practices in commercial gasifiers as well as Canadian work in this field.

Should you have any further questions relating to this report, please do not hesitate to call Dwayne Bateson at (403) 267-7129.

Yours truly,

for E.J. Barry
Vice President
Research

RJB/wp
Encl.

cc: Maureen Renaud
Science Procurement Officer
DSS

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ABSTRACT

This report reviews the status of technologies for the removal of pollutants such as particulates, sulphur gases, hydrogen chloride and alkali metals from coal derived gases. The presence of these pollutants can cause corrosion and erosion in gas turbines when used in integrated gasification combined cycle power generation.

A review was carried out of the literature on hot gas cleanup published since 1983. The review of the research results, expected performance and cost information were used in an evaluation of the technologies. In many cases, development is at an early stage and little cost information was available.

Cleanup systems used on commercial or near commercial gasifiers were reviewed. Texaco, Shell, Dow, BGC/Lurgi and KRW gasifiers were included. Only in the case of KRW was hot gas cleanup contemplated. Cleanup systems currently in use are low temperature, conventional systems similar to those used for natural gas sweetening.

Research work in hot gas cleanup being carried out in Canada by federal and provincial government agencies, universities and industry was reviewed. While considerable work has been done in gasification, little has been done directly in hot gas cleanup research.

RÉSUMÉ

Le présent rapport expose l'état actuel des techniques de dépollution des gaz issus de la combustion du charbon, par extraction de divers polluants, notamment les particules, les gaz sulfuriques, l'acide chlorhydrique et les métaux alcalins. La présence de ces matières polluantes provoque la corrosion et l'usure des turbines à gaz dont on sert d'une part pour produire de l'électricité et, d'autre part, comme instrument de gazéification.

Les auteurs du rapport se sont penchés sur la documentation publiée depuis 1983 sur les procédés de dépollution des gaz chauds. L'évaluation des technologies existantes s'est fondée sur l'examen des résultats des travaux de recherche, ainsi que sur le rendement et les coûts prévus. Dans plusieurs cas, la mise au point de ces techniques ne fait que commencer et peu de données sont disponibles sur les coûts.

Les systèmes de dépollution auxquels on a recours dans les gazéificateurs de type commercial ou para-commercial ont été examinés, notamment ceux de Texaco, Shell, Dow, BGC/Lurgi et KRW. Seul KRW avait envisagé la dépollution des gaz chauds. Les systèmes d'épuration qui sont en exploitation à l'heure actuelle sont tous des systèmes classiques à basse température, semblables à ceux dont on se sert pour l'adoucissement du gaz naturel.

Les auteurs du rapport se sont aussi penchés sur les recherches menées actuellement au Canada par des organismes fédéraux et provinciaux, des universités et l'industrie. D'importants travaux ont été entrepris dans le domaine de la gazéification, mais les recherches portant directement sur la dépollution des gaz chauds sont pratiquement inexistantes.

EXECUTIVE SUMMARY

Introduction

This study was carried out to review the status of technologies for the removal of particulates, sulphur gases and other contaminants from coal derived gas streams at high temperatures and pressures. Future applications of this technology are envisaged in integrated gasification combined cycle power plants, pressurized fluidized bed boilers and applications of coal gasification such as fuel gases and synthesis gas for chemical production.

Currently available systems operate at low temperature and the use of expensive heat recovery trains is required to maintain the system efficiency. The potential benefits of cleanup at high temperature are considerable, and in the case of integrated gasification combined cycle power plants, result in increased efficiency and lower cost electricity.

Cleanup Requirements

The gas produced by coal gasification processes contains particulate matter (mainly coal char and ash), hydrogen and carbonyl sulphides, hydrogen chloride and alkali metals. If the gas is used as a fuel in gas turbines, the presence of these components can result in corrosion, erosion and deposition in the turbine and hot gas path. This severely reduces the operating life of the machine and increases maintenance costs.

Since coal gasifiers differ in their operating characteristics, the range of contaminant levels and cleanup requirements varies considerably. Gas turbine fuel gas quality requirements have not been completely defined and some disagreement on the cleanup requirements exists between manufacturers. This is particularly true with regard to

the levels of chloride and alkali contamination. There is some evidence that these contaminants in coal derived gases are less of a problem than is the case with fuel oils.

Literature Review

A review was carried out of the published literature on hot gas cleanup. Focused on material published since 1983, the review covered particulate removal, desulphurization, alkali and hydrogen chloride removal. The review considered research carried out, expected performance and cost information if available. In many cases, development is at an early stage and little cost information was available.

Particulate Removal

Particulate removal technologies have been developed based on a range of physical phenomena. Five capture mechanisms are important: inertial impaction, diffusion, gravitational settling, direct interception and electrical migration. The dominant characteristic in all cases is the particle diameter. Because of earlier interest in pressurized fluid bed combustors, the development of particulate cleanup devices is further advanced than those for other cleanup needs.

In addition to the more commonly used particulate collection devices such as cyclones, electrostatic precipitators and baghouses, a number of other more advanced devices are under development. These include the ceramic cross flow filter, static and electrostatic granular bed filters, moving granular bed filter, electrocyclone and the acoustic agglomerator. These devices were reviewed to determine status of development and potential for commercialization. The results of this review can be summarized as follows:

Particulate Removal Device	Comments
Cyclones	Used for many years at high temperatures. Simple device. Particle removal limit 10 microns approximately. Commercially available. Development of unit with vortex collector pockets at Cardiff University, and electrocyclone at General Electric in progress. Used in many gasifiers as first stage of cleanup.
Electrostatic Precipitators	High temperature and pressure assists particulate collection. Low pressure drop collection devices, but serious materials problems likely in reducing atmospheres. Large pressure vessel required to enclose device. Development by Research Cottrell and Denver Research Institute in progress in pressurized fluid bed combustor test unit.
Granular Bed	Widely used at temperatures up to 450°C. Filter beds can be packed, moving or fluidized. Also used in Japanese fluid bed gasifier test facility. Development of moving bed unit in the US by Combustion Power Company. Tested with good results on pressurized fluid bed combustor test unit. Rather complex system on commercial scale.
Barrier Filters	Very promising device. Materials under consideration include ceramics based on alumina and silicon carbide in the form of blankets, woven fabrics or rigid candles. A ceramic cross flow filter and porous candle filter under development. Lab scale tests show good performance.
Bag Filters	Tests carried out with woven ceramic fabric by Westinghouse and Acurex Corporation. Moderate success. Good efficiencies, easy cleaning. Good potential for future.
Acoustic Agglomeration	Under development by Aerojet Energy. High intensity sound induces agglomeration of small particles removable by cyclone. Proved in principle, development of high level noise source completed. Could be useful concept.
Dry Plate Scrubbers	Developed by Air Pollution Technology. Shallow moving bed of particles removes dust from gas passing through. Incoming particles charged and part of the field imposed to enhance capture of small particles. Tests show some promise, with high capture of small particles.

After evaluating the devices, it was concluded that ceramic cross flow filters and ceramic fabric bag filters were the most promising devices.

Desulphurization

Desulphurization processes were also reviewed. Materials being researched include zinc ferrite, mixed metal oxides such as cobalt, copper or zinc, and molten alkali metal carbonates. These processes operate at different temperatures and offer a range of collection efficiencies. Calcium based sorbents can also be used, both in external cleanup devices and in fluid bed gasifiers as a sorbent in the bed.

These processes have generally not been developed to the point where they can be considered as commercial. As yet, no detailed costs are available. The processes can be summarized as follows:

Desulphurization Process	Comments
Calcium Based	Limestone or dolomite based, in-bed with fluid bed or external for other gasifier types. Up to 95% capture demonstrated by KRW. Low cost sorbent, spent material disposed of with ash. To be demonstrated in Appalachian project.
Zinc Ferrite	Developed by KRW to demonstration status. Regeneration of spent material required. Good prospect, particularly for fuel cell applications. To be demonstrated in Appalachian project.
Solid Supported Molten Salt	Development to bench scale carried out by Battelle Pacific Labs for use in fuel cell applications. Shown to remove sulphur to 1 ppmw levels. Regeneration carried out at high temperatures. Process is a long way from commercial use.
Mixed Metal Oxides	Advanced process shown in lab scale work to remove sulphur to the 1 ppmw range. Also removes HCl. Bench scale work being carried out by IGT and CalTech. Commercialization is long-term.

Desulphurization Process	Comments
Iron Oxide	Provides good performance but at relatively low temperatures. Used in the CMRC pilot scale gasifier cleanup system in Japan. Complex regeneration process. Not considered a likely candidate for use in future applications.

Alkali Removal

Removal of alkalis from gas streams is difficult to achieve because of the problems in detection of low level concentrations. An added difficulty in the development of practical systems is a lack of definition of gas turbine tolerance limits for these pollutants. Some research indicates that the bulk of the alkali is condensed on the particulate material and removed in the filters.

Several processes for alkali removal have been developed in the US which can be summarized as follows:

Alkali Removal Process	Comments
Fixed Bed	Two processes developed, activated bauxite by Argonne Labs, and emathlite by Westinghouse. The activated bauxite process removes up to 99.8% of the alkali and is regenerated. Spent emathlite is disposed of and removes about 80% of the alkali. Bench scale tests only. Commercialization some time away.
Additives	Concept is to inject a solid collector into flame to capture alkali metals. Activated alumina, kaolinite and powdered limestone are candidate materials. Work is at early laboratory stage using a test facility to simulate oxidizing and reducing flames.

Hydrogen Chloride

The cleanup requirement for this has been defined only for fuel cell applications which have a very low tolerance for chlorides. For other applications involving gas turbines, the requirements are not expected to be as exacting. Existing removal processes are designed to

operate at moderate temperatures and are not expected to be applicable for hot gas cleanup.

A number of processes are under development for fuel cell applications to remove hydrogen chloride to less than 1 ppmw. These can be summarized as follows:

Hydrogen Chloride Removal Process	Comments
Fixed Bed	Physical Sciences are screening naturally occurring materials to select a sorbent. Alkali carbonates are best candidates. The mineral shortite was selected for tests. SRI International carried out tests on shortite, nahcolite and a commercial catalyst. Nahcolite showed up to 90% capture.
Molten salt	Battelle solid supported molten salt process shown to remove chloride to less than 1 ppmw at bench scale. IGT tested mixtures of lithium and sodium carbonate to remove more than 99% of the hydrogen chloride. This material is non-regenerable.

Review of Commercial Gasifier Cleanup Systems

A brief review was carried out of the cleanup systems used on commercial or near commercial gasifiers. Suppliers were also contacted to provide information concerning any plans to utilize hot gas cleanup systems. This produced a limited response because of the proprietary nature of the processes.

Processes reviewed were Texaco, Shell, Dow, BGC/Lurgi and KRW. Only in the case of KRW was hot gas cleanup contemplated. Dow advised that it was tracking developments in this area and would be ready to apply the technology once it had been proven commercially.

Cleanup systems currently in use are low temperature, conventional systems similar to those used for natural gas sweetening. Typical processes are Selexsol and Rectisol for acid gas removal, followed by

Claus or Stretford for sulphur recovery. Particulate removal is by cyclone as a first stage, followed by water scrubbing. This also assists in cooling the gas for the sweetening stage.

KRW is planning to use cyclones and ceramic filters for particulate removal. Sulphur will be captured in the fluid bed gasifier and final cleanup carried out in a zinc ferrite bed. The gas will be cooled only sufficiently to meet the requirements for the zinc ferrite system and for the fuel gas feed to the gas turbine.

Hot Gas Cleanup Research in Canada

Research work being carried out in Canada on this topic was reviewed. This review covered federal and provincial government agencies, universities and industry. It was concluded that little work has been carried out.

Although the wider subject of coal gasification has received considerable attention, only CANMET has been involved in hot gas cleanup research. The aim of this has been to develop low cost sorbents which can be used and then discarded. Several waste materials from metal extraction have been tested with considerable success.

CANMET has also contracted work on particulate removal to the University of British Columbia. Tests were carried out on three particulate cleanup devices using an atmospheric gasifier to provide the hot gas. A conventional cyclone, a vortex pocket cyclone of the Cardiff design, and a granular bed filter were tested. The results obtained were in reasonable agreement with other published data.

No work has been identified by Canadian industry, although there has recently been considerable interest in coal gasification by utilities.

Conclusions

The most promising developments for particulate cleanup are ceramic cross flow filters and ceramic bag filters. These devices have shown good collection efficiency and can be readily back-cleaned. Although some materials and fabrication problems are still to be solved and prolonged tests in realistic atmospheres are still to be carried out, there is reasonable cause for optimism on the prospects of successful application.

A number of different desulphurization processes are under development which will offer removal efficiencies in excess of that required for the U.S. New Source Performance Standards. At present, none of these processes can be considered commercial.

Development of alkali cleanup methods is being hindered to some extent by a lack of definition of cleanup requirements. Actual cleanup needs for gas turbine applications will have to be more closely defined.

Most work in chloride removal has been directed at fuel cell applications. Allowable chloride levels for gas turbines still have to be defined. It is believed by some workers in the field that the effect of chlorides from coal derived fuels is not as significant as from liquid fuels.

All existing commercial gasification processes utilize conventional low temperature gas cleanup, with the exception of hot cyclones used in some processes to recycle unburned char to the gasifier. Should hot gas cleanup processes be developed to commercial status, there is no reason to doubt that they would be adopted by the process developers to provide cost savings and efficiency benefits.

Recommendations

Having completed this review of the state-of-the-art of high temperature, high pressure gas stream cleanup, the following recommendations are presented:

- Continue to monitor the progress of hot gas cleanup research in the US.
- Develop joint programs with US research teams.
- Carry out engineering studies to evaluate the impacts of hot gas cleanup on costs and efficiencies of IGCC power plants.
- Carry out research work to identify acceptable levels of alkali and chloride in gas turbine fuel gases.

ABBREVIATIONS

Abbreviation	Full Title
CMRC	Coal Mining Research Centre
DOE	Department of Energy
EPRI	Electric Power Research Institute
ESP	Electrostatic precipitator
HTHP	High Temperature, High Pressure
IGCC	Integrated Gasification Combined Cycle
IGT	Institute of Gas Technology
KRW	Kellogg, Rust Westinghouse
METC	Morgantown Energy Technology Centre
NSPS	New Source Performance Standards
PDU	Process Development Unit
PFBC	Pressurized Fluid Bed Boiler
SSMS	Solid Supported Molten Salt
UBC	University of British Columbia
VCP	Vortex Control Pockets

SI Unit Conversion

SI Unit	Multiply By	To Obtain Imperial Unit
Bar	14.5	PSI
°C	Temperature °C x 1.8 + 32	°F
g/Nm^3	0.437	grains/SCF
mg/Nm^3	0.437×10^{-3}	grains/SCF
kg	2.205	lbs
L/S	0.2119	CFM
m	3.2808	ft
m/s	196.86	ft per minute
cm/s	1.9686	ft per minute
m^3	6.2898	Barrels
m^3/s	2119.2	CFM
Nm^3/hr	0.5887	CFM
mm	0.03937	ins
MPa	145.03	PSI
kPa	0.145	PSI
mg/MJ	0.002328	lbs/million BTU
MWth	3.412	million BTU/hr
micron	0.03937	1/1000 inches
t/d	1.1025	short tons/day

PART 1

INTRODUCTION

PART 1 - INTRODUCTION

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1-1 Comparison of Gasification Hot and Cold Cleanup System Costs and Efficiencies

1.1 INTRODUCTION

The objective of this study is to review advanced cleanup concepts for controlling or removing contaminants from high temperature, high pressure (HTHP) gas streams to determine their overall technical and economic feasibility for commercialization. Future applications could include coal gasification for integrated gasification combined cycle (IGCC) power plants, fuel gas, synthesis gas or synthetic natural gas, as well as pressurized fluid bed combustion (PFBC) boilers and direct coal fired diesels or gas turbines.

Commercially available gas cleaning systems operate at low temperature and total recovery of energy through the use of heat exchangers is required to maintain the system efficiency. This adds to the complexity and to the cost. It is anticipated that the use of gas cleanup systems operating close to the gasifier discharge temperature will result in lower cost and higher efficiency systems.

The benefits of hot gas cleanup on the costs and performance of IGCC systems have been evaluated previously by the Morgantown Energy Technology Centre (METC) and are summarized in Figure 1-1. This shows the substantial cost reduction and efficiency improvements which can be expected to be realized through the development of advanced gas turbines and hot gas cleanup.

Cleanup requirements of the hot gas stream are dictated both by the applicable environmental guidelines and by the need to protect downstream equipment. Damage and performance degradation can be caused by erosion and corrosion due to particulate and chemical impurities such as sulphur, ammonia and alkali trace metals in the gas stream. A review of projected cleanup requirements for the major potential commercial applications has been completed by METC (92) and a summary of the findings is shown in Table 1-1. As the summary shows, there are a number of areas

where there is no consensus among suppliers of gas turbines as well as areas where needs are yet to be determined.

This report reviews the state-of-the-art of hot gas cleanup technology as well as cleanup technologies used in commercial gasifiers. Research in this subject carried out in Canada is also reviewed.

All figures andd tables are included at the end of each part, references are indicated in parentheses within the text and listed in Part 7, Bibliography. A table included in Part 7 provides cross references by subject. Part 8, Appendices, includes copies of site visit reports completed in conducting this study.

TABLE 1-1

Allowable Level of Contamination in Cleaned Gas
for Four Potentially Commercial Applications

Contaminant Categories	Pressurized Fluidized Bed Combustion/Turbine (Products of Combustion)	Integrated Gasification Combined Cycle[a] (Low-BTU Gas)	Molten Carbonate Fuel Cell (Medium-BTU Gas)[b]	Direct Coal-Fired Turbine (Products of Combustion)
Particulates	.0044 gr/scf, NSPS for coal-fired power generation (Protection of Environment 1982) 3.2×10^{-4} gr/scf, Brown-Boveri (Meyer and Edwards 1978) 1.7×10^{-4} gr/scf, General Electric (Meyer and Edwards 1978) 2.2×10^{-4} gr/scf, United Technologies (Meyer and Edwards 1978) .002 gr/scf, Westinghouse (Westinghouse Electric Corporation 1977) .01 gr/scf, METC target	.106 gr/scf, NSPS for coal-fired power generation .0077 gr/scf, Brown-Boveri (Meyer and Edwards 1978) .0041 gr/scf, General Electric (Meyer and Edwards 1978) .0053 gr/scf, United Technologies (Meyer and Edwards 1978) .048 gr/scf, Westinghouse (Westinghouse Electric Corporation 1977) .24 gr/scf, METC target .01 gr/scf, Westinghouse blast furnace gas (Westinghouse Electric Corporation 1977)	TBD[d] .0056 ppm (Vidt and others 1982)	TBD[d]

TABLE 1-1 (Cont'd)

Contaminant Categories	Pressurized Fluidized-Bed Combustion/Turbine (Products of Combustion)	Integrated Gasification Combined Cycle[a] (Low-BTU Gas)	Molten Carbonate Fuel Cell (Medium-BTU Gas)[b]	Direct Coal-Fired Turbine (Products of Combustion)
Sulfur	269 ppm, NSPS for gas turbines (Protection of Environment 1982)[c] 101 ppm, NSPS for coal-fired power generation (Protection of Environment 1982)(98% reduction)	1616 ppm, NSPS for turbines (Protection of Environment 1982) 606 ppm, NSPS for coal-fired power generation (Protection of Environment 1982)(98% reduction)	.1-1 ppm H_2S + COS (Frumerman 1982) 1 ppm (Vidt and others 1982)	269 ppm, NSPS for gas turines (Protection of Environment 1982)[c] 101 ppm, NSPS for coal-fired power generation (Protection of Environment 1982)[c](90% reduction)
Alkalis[e]	.0063 - .063 ppmw[f] .02 ppmw, GE proposed (General Electric Company 1982), METC target	.05 - .5 ppmw[f] .2 ppmv, METC target	TBD[d]	TBD[d] May be same as PFBC
Nitrogen	None; low bed temperature should keep NO_x low	25 ppmv, METC target meet NO_x standards	TBD[d] None (Vidt and others 1982)	25 ppmv METC target to meet NO_x standrds
Trace Metals	V = .0063 - .025 ppmw[f] Ca = .125 ppmw[f]	V = .05 - .2 ppmw[f] Ca = 1 ppmw[f]	TBD[d]	TBD[d]

TABLE 1-1 (Cont'd)

Contaminant Categories	Pressurized Fluidized-Bed Combustion/Turbine (Products of Combustion)	Integrated Gasification Combined Cycle[a] (Low-BTU Gas)	Molten Carbonate Fuel Cell (Medium-BTU Gas)[b]	Direct Coal-Fired Turbine (Products of Combustion)
Chlorine	None (Westinghouse Electric Corporation 1977)	None (Westinghouse Electric Corporation 1977)	.1-1 ppm (Frumerman 1982) 10 ppm HCl (Vidt and others 1982)	None (Westinghouse Electric Corporation 1977)

[a] Particulates, alkalis, and trace metals are back-calculated from PFBC.

Assumptions: 160 Btu/scf gas.
Air/gas to turbine = 5.0 (1,333°F heat rise).
Particulates are 75 percent carbon. The carbon is consumed ahead of turbine inlet.
Cold gas efficiency of gasifier is 80 percent.

[b] To obtain tolerances for low-Btu gas, divide by 2.

[c] Varies with air/coal ratios; coal HHV.

[d] To be determined; tolerances are either unknown or are not firm. Contracts planned or in place to determine tolerances.

[e] Tolerances for alkali removal are expected to be much higher if sulphur removal is to 10 ppmv.

[f] Manufacturers' standards for fuel oil-fired turbines (Westinghouse Electric Corporation 1977).

Source: Reference 92

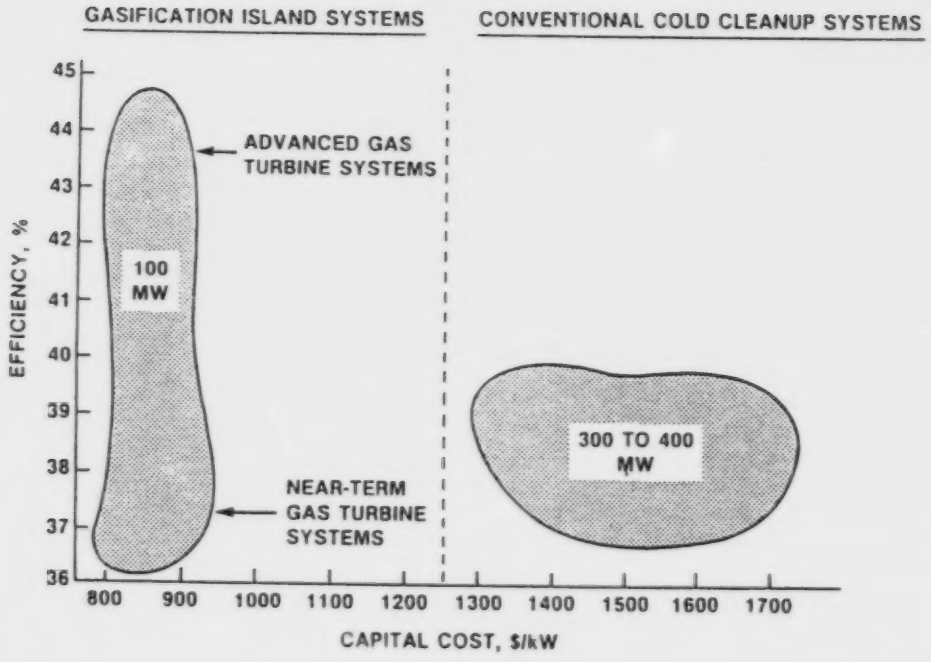

FIGURE 1-1

Comparison of Gasification Hot and Cold Cleanup System Costs and Efficiencies

Source: Reference 116

PART 2

CLEANUP SYSTEM REQUIREMENTS

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2.1 INTRODUCTION

Emerging coal utilization technologies such as IGCC and PFBC produce hot gas streams at high pressures. To achieve high cycle efficiencies, these gas streams will require cleaning to a high standard before being passed to a gas turbine or other device. In the case of the IGCC plant, the gas is used as the fuel for the gas turbine, while for the PFBC the gas is expanded directly through a turbine. There are major differences in the gas conditions and compositions. Table 1-1 shows typical gas streams for projected 100 MW power plants.

An important element in the development of IGCC power plants is particulate control to protect the gas turbine from erosion damage. It is also required to control emissions to meet the environmental limits set by the governing authority. The systems are required to clean the dirty gas streams at temperatures of 540°C to 1000°C and pressures ranging up to 3 MPa.

The hot and dirty gas streams can cause corrosion, deposition and erosion in the hot gas passages of the turbine and lead to significantly shorter operating equipment life and increased maintenance costs. This can be reduced to acceptable levels by removal of part or all of the particles from the gas flow prior to entry to the turbine and stators.

Contaminants in the fuel deposit on the surface of the turbine blades and cause slag layers to build up. This can impede gas flows or plug cooling air passages and provide sites for corrosion. In the environment prevailing in gas turbines, this is due mainly to alkali metal compounds.

Research on particles and turbine components has indicated that it is more important to control the larger particles as the smaller

particles in the less than 5 micron range tend to stay with the gas stream and do not collide with the turbine blades.

It is currently felt that a particulate loading of 0.02 g/Nm^3 for particles less than 5 microns diameter, and total removal of those larger than 5 microns, will provide sufficient protection for the turbine (8).

Much of the work on particulate removal with PFBC applications in mind is not considered to be applicable to gasification systems because of material problems. Gas from PFBC contains oxygen which helps to maintian a passive film on metal surfaces. On the other hand, gasification processes operate under reducing conditions and a gas containing hydrogen, hydrogen sulphide and hydrogen chloride which is corrosive at high temperatures. This is a severe problem for devices such as electrostatic precipitators which subject metals to raw hot gas conditions, and may prevent the use of this technology in gasification applications (22).

2.2 GASIFIER GAS QUALITY

The requirements for particulate removal devices are made more complex by the varying inlet dust loadings from different gasifiers and the varying outlet dust loadings required for downstream applications. Typical dust loadings range from 4 to 22 g/Nm^3 leaving the gasifiers or the radiant gas coolers. Outlet dust loadings can be controlled by varying requirements such as particulate emission guidelines, gas turbine fuel gas specifications, heat exchangers or other downstream equipment. For IGCC applications, it is probable that the governing requirement is not environmental emissions, but the needs of downstream equipment such as desulphurizing trains and gas turbines (22).

Coal gasifier technologies vary considerably in their operating characteristics. Information on gas stream characteristics has been compiled for the principle gasifier types, i.e. fixed bed, fluid bed and entrained flow (55), and is shown in Table 2-1. These data are presented here without footnotes and the reader should refer to reference 55 for more complete information.

The temperature and pressure ranges shown in the table are representative of the variations between processes. Temperature variations also reflect variations occuring over time with any single process. Generally, process controls are capable of controlling temperature and pressure within much narrower ranges than indicated in the table.

Particulate matter in the gas stream generally consists of high-carbon dusts and fly ash. The presence of tars in the gas can contribute to the adhesiveness of the particulates. Tar loadings in gasification gas streams have an important bearing on the design of the cleanup system because of the effects of condensation and cracking reactions. It is generally regarded by most references in the literature that tars are evolved only from fixed bed designs. However, experience with commercial designs has indicated that tars are evolved whenever the air-to-fuel ratio falls below a critical value, regardless of gasification process (55).

Cleanup requirements have been suggested by METC (91) for advanced IGCC systems and are shown in Table 2-2. Fixed bed systems, because of the low temperature of the fuel gas (550°C), are not expected to require any alkali removal. Also, because the quantity of particulates elutriated from the bed is low, cyclones are expected to provide sufficient removal for gas turbine needs. For the fluid bed gasifiers, in-bed desulphurization would control the sulphur emissions, although zinc ferrite polishing may be required. Advanced particulate removal devices will be required, but alkali removal will be required only for the higher

temperature product gases (above 750°C), where significant amounts of the alkali will remain in the vapour phase.

2.3 GAS TURBINE FUEL GAS QUALITY

The fuel gas quality can affect the gas turbine in several ways, namely, causing erosion, corrosion and fouling. Erosion is caused by the high velocity impact of particles on the turbine blading and depends mainly on particle concentration and size distribution as well as particle hardness and relative velocity. Hardness and ductility of the metal blades is also important. Centrifugal forces in the turbine tend to make the larger particles migrate outwards towards the casing in the last stages.

Fuels containing ash cause fouling, resulting in a loss of performance. This affect is more severe with smaller particles and can cause rapid reductions in performance. Corrosion in the turbine is generally caused by the alkali metals which are present in the vapour phase and condense on the metal sufaces. Small dust particles can act as the condensation surface. A level of 1 ppmw of alkali is generally considered as a desirable limit (9) although conclusive data on permissible alkali levels in hot fuel gas are not available. Another turbine manufacturer has reported a guideline of less than 1 ppmw in the fuel gas phase alkali concentrations (75). H_2S can be tolerated to some extent, but the affects of HCl are not known (24).

The affects of the presence of even low level quantities of alkalis in the gas turbine lead to a reduction in operating life of the hot components, principally in the turbine and combustion system. Figure 2-1 shows a curve of turbine life plotted against Na + K concentration (60).

Research work has been carried out at General Electric Corporate Research and Development Center on the effect of hot gas streams on turbine components (76). Other work has indicated that gas turbines operating at the higher turbine inlet temperatures necessary to achieve high cycle efficiencies require a cleaner gas than can be provided by cyclones alone (7), although the literature is not unanimous on this point.

Currently, there does not appear to be a generally accepted standard for fuel gas contaminant levels as they enter the gas turbine. Some organizations have arbitrarily adopted very conservative standards in the absence of more definitive data. One such standard (86), for gas as it enters the turbine is as follows:

Particle size (microns)	None > 10
	99% < 6
Particle loading (mg/Nm^3)	4
Alkali concentration (ppmw)	0.01

Any cleanup system which satisfies these requirements will have no difficulty in satisfying current or anticipated cleanup standards.

TABLE 2-1

Observed Gas Stream Characteristics

Gas Stream Parameter	Units	Gasifier Type: Fixed Bed	Fluid Bed	Entrained Flow	Pressurized Fluid Bed Combuster
Gas Temperature	°C	425 - 675	560 - 1,000	425 - 925	730 - 900
Pressure	MPa	0.1 - 3	0.1 - 8	0.1 - 10	0.6 - 2
Moisture Content	%	10 - 40	min 25	2 - 50	2 - 3
Carbon Dioxide Content					
Air Blown	%	5 - 9	5 - 10	3 - 7	13 - 16
Oxygen Blown	%	18 - 32	25 - 40	22 - 36	N/A
Particulates					
Constituents		Coal Ash, Char	Coal Ash, Char	Coal Ash, Char	Ash
Pre-cyclone Loading	mg/Nm^3	2,000 - 12,000	180,000	150,000	N/A
Post-cyclone Loading	mg/Nm^3	10 - 630	9,000 - 75,000	9,000 - 16,000	80 - 4,000
Particle Diameter	microns	2 - 3	20 - 30	100 - 200	4 - 15
Carbon Content	wt%	up to 80%	35 - 60	20 - 75	0.2 - 2.5
Tar Loading	mg/Nm^3	13,500 - 50,000	Variable	No Data	Very Low
Alkali Content					
Loading	ppmw	High	High	min 60 - 100	Up to 10
Vapour Phase		Present	Present	No Data	0.1 - 0.3

Source: Reference 55

TABLE 2-2

Advanced IGCC Systems and Contaminant Control Processes

Gasifier Type	Contaminant Control Method			
	Sulphur	Alkali	Particulate	Ammonia
Fixed-Bed	ZnFe	Not Needed	Cyclones	Steam Injection; Staged Combustion
Fluidized-Bed, Product Gas at 650°C	In-Bed Desulphurization and ZnFe	Not Needed	Cyclones and Advanced Devices	Not Needed if In-Bed Desulphurization is Used
Fluidized-Bed, Product Gas at 760°C	In-Bed Desulphurization and Novel Sorbents	Need for Control Not Known	Cyclones and Advanced Devices	Not Needed

Source: Reference 99

PART 3

REVIEW OF RECENT HOT GAS CLEANUP LITERATURE

PART 3 - REVIEW OF RECENT HOT CLEANUP LITERATURE

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3.1 INTRODUCTION

A literature search was carried out to identify information on hot gas cleanup. In the US, the major efforts in this area are supported by the Electric Power Research Institute (EPRI) and the Department of Energy (DOE) at METC. Annual conferences sponsored by these organizations have resulted in the publication of many papers on the subject of hot gas cleanup. These sources are listed in Part 7 of this report.

A further good source of hot gas cleanup information was work carried out on particulate removal for PFBC applications. Although the technology developed is not directly transferrable to coal gasification fuel gas streams, it provided a thorough investigation of particulate removal devices.

Work has been carried out at METC to test a number of devices under simulated coal gasification conditions. Devices tested have included ceramic cross flow filters, ceramic bag filters and electrostatic precipitators. These devices were selected for testing because of their potential for successful operation and to evaluate the operation under gasifier stream conditions with variation of parameters such as particle size distribution, filter cake stickiness, and chemical constituents. A bench scale fluidized bed gasifier is used to test and evaluate the hot gas cleanup devices.

Other work sponsored by METC has included an evaluation of ten particulate cleanup devices under development by various manufacturers. This allowed an initial assessment of relative effectiveness and cost to be made (10).

3.2 PARTICULATE REMOVAL

321 GENERAL

Particulate removal systems have been developed taking advantage of a variety of physical phenomena to capture the dust and ash particles in the fuel gas stream. The fundamental particle collection mechanisms which the particulate cleanup systems utilize can be summarized by five parameters (55): inertial impaction, diffusion, gravitational settling, direct interception and electrical migration. Values of these parameters have been calculated for a range of particle diameters for gasification conditions and are shown in Figure 3-1.

Theoretical collection efficiency calculations have shown that particle diameter was the dominant variable for all collection mechanisms. This was followed by gas flow and temperature, with the exception of interception which was independent of gas flow and temperature. Pressure was found to be insignificant for all mechanisms (55).

In addition to the more commonly used particulate collection devices such as cyclones, electrostatic precipitators and baghouses, a number of other more advanced devices are under development. These include the ceramic cross flow filter, static and electrostatic granular bed filters, moving granular bed filter, electrocyclones and the acoustic agglomerator. The status of development and the potential for use in hot gas cleanup for IGCC applications was evaluated in this part of the study.

Gas cleanup devices can be classified according to their effectiveness in removing particles of different size ranges. One such classification is shown in Figure 3-2 (86). This suggests that cyclones are not sufficiently effective for fuel gas cleanup applications.

322 CYCLONES

Cyclones are the principal option for high temperature dust removal. They have been in use for many years and have been shown suitable for removal of particles down to approximately 10 microns at relatively high efficiency. They are available commercially with capacities of up to approximately 60 m^3/s. A typical performance curve is shown in Figure 3-3. This shows removal of greater than 94% of particles larger than about 10 microns, falling off to 45% for 2 micron particles. The total pressure drop is in the 0.2 to 0.4 percent range (81).

Cyclone dust collectors have been long used to separate particulate matter from gas streams. They have the advantage of being simple devices with no moving parts and can therefore be readily adapted for use at high temperatures and pressures. Cyclones are widely used in applications such as circulating fluid bed boilers to separate the entrained char particles for return to the bed.

Simple cyclone theory considers only inertial forces. It is assumed that particles will be captured by the cyclone if the centrifugal force on the particle is greater than the aerodynamic drag force. This model predicts that capture efficiencies of 100% should be obtained for particles slightly larger than the cut size. This predicts the cut size of low temperature and pressure cyclones reasonably well but does not predict the shape of the efficiency curve. More recent work on the mechanism of particle capture in cyclones has taken the influence of turbulence into account (24).

Cyclone efficiency is known to decrease with increase in cyclone size. Prediction of collection efficiencies of cyclones operating at high temperatures has met with mixed success. It can be shown that the fundamental problem is insufficient knowledge of gas flow behaviour (2).

The influence of turbulence on the re-entrainment of small particles (less than 20 microns) is important and limits cyclone efficiencies. While the centrifugal forces cause the particles to separate, re-entrainment prevents their collection. Wall turbulence is known to be an important mechanism in this phenomenon and efforts are being made to develop methods of suppressing this turbulence with the aim of achieving a cyclone which can reduce particles in the size range greater than 5 microns to a level close to zero (53).

A number of developments are taking place in cyclone design. At University College, Cardiff, Wales, a concept known as the Cardiff Cyclone is being explored (1, 11). This design makes use of two features to achieve high efficiency collection. These are the use of a vortex weir to ensure flow symmetry from the use of only one tangential inlet. This is shown in Figure 3-4.

The major innovation used on this design is the use of vortex collector pockets (VCP's) which are positioned at various points on the separator to remove remove dust fractions. Their operation depends on the use of the main vortex to generate a weak secondary vortex in the VCP in such a way that there is no net gas flow into the pocket. Dust particles centrifuged to the wall of the main cyclone chamber enter the VCP due to inertial effects and are rapidly decelerated due to friction. The particles then fall to the bottom and are removed from the base. This is also shown on Figure 3-4.

A compact dust collector of the Cardiff design is shown in Figure 3-5. The dust containing gas enters the inlet and flows over the weir to enter the outer annulus. Coarse dust fractions are concentrated into the wall boundary layer and are removed by the first VCP. The gas and remaining finer dust then spill over into the main vortex chamber where they are removed by the second VCP. The finest material is removed from the main cell base which acts as a conventional cyclone.

This design has a number of apparent advantages over conventional cyclones. The unit is approximately one half the height of a conventional unit for a given volume of gas. Also, the use of the VCP's results in a classification action which could be used on an IGCC application to separate ash from unburned char which would be recycled to the gasifier. The separator also removes a high percentage of the smaller particles of less than 5 microns. Work is continuing to optimize the design.

A full size prototype Cardiff cyclone has been evaluated on a 3 MWth fluidized bed boiler and resulted in the reduction of solid emissions by a factor of three when compared to a proprietary multicell cyclone design. This was found to be due to higher efficiency in the sub 5 micron size range (11).

A vortex pocket cyclone of the Cardiff design was tested in a gas stream from a bench scale gasifier at the University of British Columbia (133). This was subjected to dust inlet loadings of 30,000 to 100,000 ppmw and resulted in outlet concentrations averaging 360 ppmw. This is discussed in more detail in Part 5.3 of this report.

Another development is the electrocyclone under development by the General Electric Company. This design consists of a high flow cyclone with a scroll inlet and outlet. An electrode suspended downwards through and out of the exit tube enhances particle movement to the wall. This is achieved by setting up a field between the electrode and the cyclone wall to enhance the collection efficiency.

The theoretical aim of the design is to allow large diameter cyclones to achieve efficiencies comparable with very much smaller diameter cyclones in the 250 mm range (10). Several of these units would be used in series but it is anticipated that performance will fall short of that required to allow direct feed of the cleaned gas to the gas turbine. Development is currently focussed on scaleup to larger units,

geometry improvements and performance at high temperature and pressure (68).

A high efficiency particulate separator has been developed and tested on the KRW (then Westinghouse) gasifier at Madison, Pennsylvania. The design was based on an analysis of cyclone performance which determined that small particles could not be separated because of boundary layer build-up, high turbulence levels, flow separations and the resulting unsteady flow conditions. It was also determined that at high pressures, due to increased density, the smaller particles have minimum slip in relation to the gas streamlines and are therefore difficult to separate.

The device was designed to avoid these unsteady flow conditions by operating at high velocity. Tests on actual units at 540°C and 1.725 MPa showed collection efficiencies of 99.7%. Comparative performance is shown on Figure 3-6. However, the design of the device was such that it utilized many small flow channels which became choked with dust during tests. It was felt by METC that this device was not a practical solution to the problem.

323 ELECTROSTATIC PRECIPITATORS

Electrostatic precipitators (ESPs) are one of the most commonly used devices to remove particulates from coal-fired boiler flue gases. The precipitator consists in essence of a corona discharge wire between collector plates. The working principle is that the ions or electrons from the corona wire charge the dust particles and the electric field between the corona wire and the collector forces the charged particles particles to migrate to the collector. The minimum operating voltage is the voltage at which the electrons start being emitted from the corona wire and the maximum occurs when sparks are formed between the corona and collectors (24).

Conventional units usually operate at less than 300°C, although some units are in operation at up to 450°C. Research on the application to high temperature and high pressures has been on going since the 1960s. This work has shown electrostatic precipitators to be very suitable for use in such applications but that there are considerable practical problems to be solved. However, the physics of electrostatic precipitation shows thoeretical advantages at high temperature and pressure conditions. The favourable electrical effects of higher gas densities provide significant sizing and performance advantages over conventional applications.

ESPs have several advantages over filtration and cyclones at high temperature and high pressure conditions. Pressure drop is low because there is little restriction to flow. In addition to this, ESP's show little likelyhood of blockage that can be experienced with other types of collection equipment. Operation at low loads does not effect efficiency as it does with cyclones which depend on fluid velocity. There is also no drop in efficiency incurred by scaleup to the larger sizes required by commercial plants. Compared with conventional applications, at HTHP conditions the ESP design can be much more compact because of the higher gas densities and because of the higher operating field strength.

Research-Cottrell in the United States has carried out research in this area since the early 1960s. A number of applications have been carried out, the most recent one being at the Curtiss-Wright PFBC facility in New Jersey. Tests were carried out at temperatures of 750°C to 800°C and pressures around 500 kPa. Efficiencies of up to 99.5% were achieved (50). The test precipitator is shown in Figure 3-7. An ESP design has been proposed by Cottrell Environmental Sciences for commercial use in PFBCs is a plate type unit enclosed in a horizontal pressure vessel. This is shown in Figure 3-8. The Denver Research Institute has also carried out development work for PFBC applications (38).

For applications at conditions in excess of 875°C and 700 kPa further research is required. The collection system must be designed taking the composition of the particulates from the gasifier outlet gases into account. These particulates have a high carbon content and are relatively conductive and exhibit relatively low electrical resistance when compared to PFBC ash.

The use of ESPs is being evaluated by METC at its Hot Gas Particulate Test Facility. A test module built by the Denver Research Institute is used. This is shown in Figure 3-9.

Two corona configurations have been tested to determine their voltage and current characteristics, and has shown that power consumption is fairly high. This, however, could be a function of the small scale of the test equipment.

Tests planned to be carried out on the METC 150 mm diamater fluidized bed gasifier are aimed at determining the most frequent and severe upset conditions on the operation of the ESP, to evaluate the operation as a control device on a coal gasifier, and to provide data for a commercial scaleup of the pilot plant unit.

Research is also being carried out at the University of Essen to develop a ESP for use in PFBC and coal gasification. This has now reached the pilot stage and is shown in Figure 3-10. The work carried out has been directed at the determination of conditions necessary for a stable corona discharge under varying temperature, pressure and corona geometry. This has shown that the combination of high temperatures and pressures likely to be experienced in gasification systems are exactly those required for stable operation. This research program has shown that ESPs are a very good prospect for use in future gasification processes.

324 GRANULAR BED FILTERS

Granular bed filters have been used over the past 80 years to clean dust laden gases at temperatures up to 450°C. Collection mechanisms involved in this device are gravity settling, inertial impaction and direct interception. They can be classified as packed, moving and fluidized beds. Packed and fluidized beds have to be cleaned intermittently by some reverse flow procedure; moving beds can be operated continuously. A number of research projects have been carried out using granular beds.

The Japanese fluid bed gasification project carried out by the Coal Mining Research Centre (CMRC) has developed a moving bed granular filter to clean the gas at a temperature of 460°C. The unit has primary and secondary stages and treats 4500 Nm^3/h of gas at a pressure of 1.9 MPa. A schematic of the system is shown in Figure 3-11. Silica sand can be used as a media for temperatures up to 800°C.

An inlet dust concentration of 3 g/Nm^3 is cleaned to a target concentration of 5 mg/Nm^3. An efficiency of 99.8% is claimed. Approach velocities of 0.1 to 0.2 m/s are used for both filters. The silica sand moves down through the filters and is drawn out of the pressurized system by a lock hopper. From there the media is passed over a vibrating screen where the dust is extracted. A bucket elevator then raises the media to the top of the filters for re-use.

The system has undergone a series of tests since the end of 1983. The required performance was attained, however some problems have been experienced due to corrosion caused by chlorine and sulphur. Special ceramic valves have also been developed to seal the hot gas and the silica sand (5).

Research in this area has also been carried out by METC. A moving bed granular filter was developed under contract by the Combustion

Power Company (13, 65). This unit is a screenless design, with the media (2 to 3 mm diameter alumina oxide beads) being contained in vessel with a cone shaped base as shown in Figure 3-12. The dirty gas enters the filter element through an inlet pipe which is submerged in the filter granules.

Particles are removed from the gas stream as it moves upwards through the bed. The filter media is continuously removed from the bottom of the vessel and new material is added through the return legs. The dirty media is cleaned as it is transferred back to the top of the element. Concentrated particulates in the cleaning gas stream are passed to a small baghouse for final particulate capture. A number of filter elements are contained in a single pressure vessel, also shown in Figure 3-12.

Tests have been carried out on a sub-pilot scale at atmospheric pressure and temperatures of approximately 900°C demonstrated succesful operation over a 1500 hour test. Collection efficiencies of 99% were obtained with pressure drops in the 6 kPa range and degradation of the filter media did not occur. Pilot scale tests are currently underway in the New York University PFBC test facility to determine the performance under pressurized conditions. This will be used to assess the technology for commercial scale use in PFBC (106).

This concept appears to be rather complex mechanically and will be a challenge for design at high operating temperatures.

Two other granular bed filters developed by METC have proved to be less effective. General Electric evaluated an electrostatic granular bed filter which consisted of a moving bed of granular media contained between two retaining walls that are made of widely spaced louvres. Dust-laden gas enters the unit and flows across the moving bed of granular media. A corona particle charger is employed to charge the particles as they pass through the unit and enhance the collection

efficiency of the smaller particles. Tests have shown that the front faces of the louvres become blocked by a build up of dust. Further tests carried out at conditions more closely duplicating PFBC operation confirmed the problem.

Westinghouse examined the concept of static granular bed filters as shown in Figure 3-13. This is an adaptation of an existing filter design by Ducon and consists of multiple stages of fixed beds containing a shallow bed of granular material. Particles are collected as the dirty gas passes down through the beds, and the media is cleaned by fluidizing the bed material. Tests showed that this method was not effective due to poor distribution of the cleaning gas. Some beds were blown away completely while others were not cleaned at all. While this concept has not been completely abandoned, considerable further development will be required before it can be considered viable.

The University of British Columbia has carried out tests of a granular bed filter (133). The filter was installed downstream of a vortex pocket cyclone and fed with a dust laden gas stream from a pilot scale spouted bed gasifier. Efficiency during the tests was low, ranging from 15% to 57%, but was found to be in line with results published in the literature for particles below 2 microns in size. This is discussed in more detail in Part 5.3 of this report.

325 BARRIER FILTERS

Barrier filters operate in a similar manner to baghouses. A filter cake builds up on the outside of the element and the efficiency achieved is largely dependent on the maintenance of a cake which covers the complete filter surface. In the application to coal gasification fuel gas streams, there is some concern that the carbon particles in the gas stream may prevent the build up of a satisfactory cake, and there is some evidence that, in fact, this does occur.

Barrier filters are one of the most promising methods of hot gas particulate cleanup and a number of developments are being carried out in the US under contracts from METC and EPRI. Suitable filter materials include ceramics based on alumina, alumina-silicates, zirconia and silicon carbide in the form of blankets or bats, woven fabrics and rigid candles. The candle filters appear to offer a good compromise between initial strength and resistance to degradation (7). Rigid filters are discussed below.

A very promising technology developed by Westinghouse under contract from METC is the ceramic cross flow filter (13). In design and operation, it is similar to a baghouse, except that rigid ceramic filter elements are used instead of bags. The concept is shown in Figure 3-14. It consists of layers of thin, flat, corrugated, porous ceramic material placed such that consecutive layers are orientated to provide channels which are at 90° to one another. One of the four sides of the filter element is sealed. Gas enters the filter through the openings of the corrugations on the two sides which are perpendicular to the sealed end and permeates through the ceramic before exiting through the openings on the side that is parallel to the sealed end. The filter elements are periodically backflushed to remove the particles which build up on the dirty side of the dividing walls.

For full-scale use, multiple filter elements are connected to an exhaust manifold by means of the gas-exit end of the filter. Figure 3-15 shows how several filter and manifold assemblies are arranged in a single pressure vessel. One important advantage of this type of filter is the large surface area to volume ratio of the module which is approximately ten times that of a bag filter. This reduces the size of the pressure vessel required to handle a given volume of gas.

Testing has initially been carried out with PFBC applications in mind. Tests were carried out under simulated and actual PFBC operation, at temperatures of up to 825°C and pressures to 1.03 MPa.

Results showed that the filters had efficiencies in excess of 99.9% and operated in fact as absolute filters. Even when operated under particulate loadings up to 25 times the nominal, the efficiencies were maintained with increased frequency of cleaning.

Subsequent test programs have been carried out on a pilot scale fluid bed gasifier at METC at conditions up to 850°C and 2.07 MPa using raw fuel gas or desulphurized fuel gas at flows of 8 to 32 L/s (8). Approximately 250 hours of testing were carried out at particulate loadings between 0.71 g/Nm^3 and 14.1 g/Nm^3. This range was selected to represent the particulate loadings from gasifiers with one or with two cyclones. Performance was generally good with moderate pressure drops of about 2.5 kPa maintained; however, some delamination of the modules was experienced. Westinghouse is of the opinion that this problem is likely to be solved by modifications to the manufacturing process. A summary of test results is given in Table 3-1.

Current plans are to install a full-scale module at the New York University PFBC pilot plant. This will require several major scale-up problems to be addressed for the first time, including the mounting, operation and cleaning of several elements in a single plenum and the parallel operation of several modules in a tubesheet.

Westinghouse is also working with EPRI on the development of a porous ceramic candle filter made from silicon carbide (79). This is being developed principally for PFBC use, but also has applications in gasifier fuel gas cleanup. Tests have been carried out on a single 1.5 m long candle filter at 815°C and 1.15 MPa over a 2000 hour operating and pulse cleaning cycle. A drawing of the candle filter is shown in Figure 3-16.

Results of tests gave an overall efficiency exceeding 99.98%. Pressure drops are relatively high at around 25 kPa. The candle permeability decreases over an initial conditioning period, and then remains

essentially constant. Some flange failures were encountered, but redesign of the support flange to a hemispherical shape is reported to have eliminated the problem. Tests are planned to be carried out at the Grimethorpe PFBC test facility in the U.K.

Tests on a similar design of ceramic candle filter have been carried out by the Coal Research Establishment (CRE) of the National Coal Board (NCB) in England, using a fluidized bed gasifier to provide the gas stream at temperatures around 950°C and atmospheric pressure. Three different candle filter compositions were tested for periods of 45 to 220 hours. The conventional alumina material showed a steadily rising pressure drop which caused the filter to become choked by a build up of dust after a short time. The two others containing ceramic fibres showed a steady residual pressure drop after a running time of 40 to 80 hours and exhibited collection efficiencies of greater than 99% (86).

There is some indication that the reducing atmosphere of the gasifier fuel gas leads to a chemical attack on the candle material, which then results in decreased permeability and higher pressure drops (101).

326 BAG FILTERS

Bag filters are one of the two most commonly used particulate cleanup devices on conventional power plants. Dirty gas generally flows from the outside of the bag through to the inside, leaving the dust as a cake on the outer surface. The dust is periodically removed by shaking, reverse flow or a pulse of high pressure air (85). The use of baghouses on hot gas cleanup systems is fundamentally one of developing a suitable material for operation at high temperatures and of developing a suitable design which can be contained in the required pressure vessel.

In the U.S. METC and EPRI have sponsored tests of ceramic bag filters for high temperature applications. The collection mechanism is

identical to that of conventional filtration. Although previous tests have shown that ceramic filters could be applied to oxidizing gas streams from PFBCs, some mechanical problems existed. Failure of the fabric or sewing thread, and fabric embrittlement was observed (8).

Westinghouse is working with two materials. The first is Carborundum Fibersil cloth which is formed into a bag by stitching with thin Inconel thread. Tests carried out at 815°C and 1.15 MPa in a simulated PFBC environment showed high efficiency but resulted in failure of the seam. The other material used was 3M Nextel woven ceramic fabric. The bag was prepared as a seamless tube and tested in similar conditions. Efficiencies exceeding 99.98% were achieved and showed significant improvement over the earlier tests. Tests have also been carried out using felted bat type filters which provided high collection efficiencies but formed deposits on the outside which proved difficult to remove.

Acurex Corporation has been working with METC to develop ceramic bag filters for PFBC and gasification fuel gas cleanup. Simulated PFBC tests were conducted at the Westinghouse test facility and the calculated overall efficiency of collection was found to be in excess of 99.99%. Accelerated life tests showed no significant deterioration after two years' equivalent operation. Subsequently, a unit containing 15 bags was tested in the Curtiss-Wright PFBC test facility and the indications were that high efficiencies can be achieved. The test unit is shown in Figure 3-7 (13).

More recently, the Acurex fabric bag filters have been tested on the METC fluid bed gasifier (88). Several candidate filter materials were pre-screened in a laboratory simulated environment to select the material to be used in the gasifier tests. The selected filter was then tested in the fluid bed gasifier at the following operating conditions:

Temperature	500 to 875°C
Pressure	0 to 2.07 MPa
Dust load	0 to 24 g/Nm^3
Face velocity	Up to 5 cm/s
Pressure drop across filter	Up to 6.2 kPa

The filter size selected was 3 m long by 0.15 m in diameter and the material was a woven fabric containing Nextel and Fibrafax, giving a "fuzzy" texture. This material was found to have a good efficiency in the presence of significant amounts of gasifier char. The tests were conducted to obtain information on the particle collection efficiency, cleaning requirements and pressure drop characteristics as well as some indication as to the durability of the material. A total of 250 hours of testing was planned.

During the initial 110 hours of testing, outlet particulate dust loadings were observed to fluctuate inconsistently. On inspection, it was found that the bag had been stretched approximately 200 mm because of the method of support used. The result of this was the formation of pinholes in the fabric which lead to the erratic performance. The results of the initial 110 hours of testing are given in Table 3-2. It was felt that the bag stretching could have prevented the formation of a sufficient filter cake and resulted in the lower efficiencies. The problem of the bag support will be corrected before completing the test (8).

On the basis of the tests carried out to date, the bag filter seems to be a good candidate for hot gas cleanup systems.

327 ACOUSTIC AGGLOMERATION

A hot gas cleanup system based on the physical phenomenon of acoustic agglomeration is being developed for METC by the Aerojet Energy

Conversion Company. This concept is based on the use of a high level noise source to induce oscillations in the flow of the sub-micron particles and by causing them to collide, agglomerate the small particles into larger particles which then can be removed by more conventional means such as cyclones. The concept is illustrated in Figure 3-18.

A simplified explanation of the principle is that the acoustic wave generates an oscillating gas velocity as it travels through the aerosol. Particulate material suspended in the gas stream oscillates with the vibrating gas because of drag forces induced by the gas viscosity. The amount of motion depends on the particle size, with the smallest particles following the gas flow most closely. Larger particles, because of their increased mass, will essentially stand still depending on the value of the inertia-to-drag forces and the acoustic frequency. This difference in amplitude of motion between the different particle sizes causes them to collide (36). The performance expected of this device is shown on Figure 3-19. The majority of particles below about 5 microns are agglomerated and that the mass percent greater than 10 microns, the approximate cut size for cyclones, is increased significantly.

The major components in the system are the sound source, the agglomeration chamber and a conventional cyclone. Two sound sources have been investigated, an air driven siren and a combustion pulsor. Exposure to a sound level of 160 dB for three seconds is required. The combustion pulsor is a small combustor attached to an acoustic horn. Premixed air and natural gas is burned in an unstable mode of combustion to give high intensity pulsations of hot gas which are transformed in the horn to acoustic waves. An advantage of this approach is that the heat generated goes directly into the hot gas and is utilized in the downstream equipment. Sound levels of up to 173 dB at 1 MPa pressure have been achieved. An air powered siren has also been developed using an electric motor to give a sound level of up to 165 dB at 1 MPa pressure (104).

Development of the sound sources has been completed and tests at the Pennsylvania State University test facility have been started. Preliminary results and projected costs have been evaluated. This concept looks very promising although it is still at an early stage of development.

328 DRY PLATE SCRUBBERS

A final particulate cleanup method being evaluated by METC for PFBC applications is the Air Pollution Technology dry plate scrubber. The operating principle of this device is to remove particles from the dirty gas stream as it passes through shallow moving beds of granular material. Several different configurations are possible and are shown on Figure 3-20. The horizontal plate design was selected by METC for development.

To increase the collection efficiency for small particles, incoming particles are charged and the final one or two stages have an electrical field imposed on them. The collection granules are continuously removed from the bottom of the dry plate scrubber, cleaned, and reintroduced at the top.

A series of tests have been carried out. For cold flow tests, four stages of beds were used, using 0.68 mm diameter alumina beads as the bed material. Collection efficiencies of greater than 99% were measured. This was followed by tests under atmospheric FBC conditions. This showed that the perforated support plate would not plug up with ash.

Tests have been carried out at a temperature of 900°C and a pressure of 1 MPa using a three stage dry plate scrubber, with the last two stages being electrically augmented. High efficiencies have been achieved, and, of particular interest, was an increase in the collection efficiency for particles smaller than 3 microns when a second polarizing stage was added.

329 EVALUATION

In evaluating the technologies being developed for particulate cleanup, it should be taken into consideration that the majority of these devices were first developed for PFBC applications. It was only as interest in gasification has grown in the last few years that this application has been considered. Differences in hot gas characteristics between PFBC and gasifiers are significant (see Table 2-1), the most important being the extremely hostile environment of gasifier gas streams due to the presence of CO, H_2, H_2S and alkalis at high temperatures. The other major difference is the presence of char in the gasifier gas streams. This prevents the build up of an adequate cake on the surface of filters and reduces the collection efficiences.

These differences complicate the already exacting task of removing particulates at high temperatures. The reducing atmosphere in the gasifier results in aggressive corrosion of metals and alloys and make the use of electrostatic precipitators, or other devices using electrostatic methods, unlikely unless the problem of suitable material selection can be overcome. An example of this problem is the results of tests carried out at KRW Energy Systems using sintered metal filters which led to the rapid destruction of the metal because of chemical attack.

Several evaluations of particulate devices are available in the literature. Reference 22 provides a slightly pessimistic perspective by EPRI. High temperature corrosion is seen as a major unsolved problem. It should be noted that this study is directed more at medium heating value gas which has greater corrosion potential than low heating value gases. Another difficulty is the variation in dust loadings from the various gasifier types and a similar variation in cleaned gas standards required by manufacturers of gas turbines and heat exchangers or downstream desulphurization equipment.

The EPRI assessment of cleanup devices is shown in Table 3-3 and selects ceramic candle filters as being the best choice should cyclones be incapable of providing adequate levels of removal.

The majority of research and development work in this field has been carried out by DOE. Two review papers are of interest in evaluating the technologies. In the first (55), an attempt is made to assess the technologies which have been developed for PFBC applications for use in coal gasification processes. This review covers ten devices which are listed in Table 3-4. The work was carried out with the following aims:

- To determine the differences between PFBC and coal gasification gas stream conditions;
- To determine the expected performance characteristics for these devices under gasification conditions;
- Evaluate the devices in order of expected suitability for gasification; and
- To determine the future research and development needed to improve the suitability of the devices for gasification.

At the time the work was carried out, little testing of the devices under actual or simulated gasifier conditions had been done. Therefore, it was necessary to carry out a thoeretical study of performance using performance models previously developed. Three sets of simulated gasifier conditions were evaluated:

o 425°C and atmospheric pressure	Fixed bed
o 650°C and 0.5 MPa	Fluid bed
o 875°C and 2.0 MPa	Entrained flow

The results of this are shown in Table 3-5. Details of the collection efficiencies are a function of particle size. All but two of the devices showed the potential for meeting the NSPS efficiency target of an outlet particulate loading corresponding to 13 mg/MJ. This report did not provide any estimate of costs.

A very comprehensive evaluation of ten particulate cleanup devices was carried out by METC (10). Completed for PFBC applications only, the comments given earlier in this section regarding the differences in service requirements between the two applications should be considered. The devices evaluated were the same as those shown in Table 3-4. Because each device was at a different stage in development, estimates of performance were prepared based on normalized conditions. The operating conditions assumed were 870 to 900°C at a pressure of 1 MPa. Cleanup specifications were based on meeting NSPS standards and gas turbine inlet requirements as specified by General Electric.

The current development status of each device is summarized in Table 3-6. This shows the range of design flows and operating conditions attained. Based on this information, the commercial size design work carried out by the developers, the design normalization work and the cost analysis of the normalized designs, an evaluation was carried out to put the development progress and the potential commercial viability of each device into perspective. The opinions of experts in the field have been solicited relating to a number of parameters which were felt to be crucial to the success of each particulate cleanup device. This resulted in the ranking of the devices in the order of expected success.

The results of this work are summarized in Tables 3-7 to 3-9. Table 3-7 shows the cleanup efficiencies after normalization of the test data. Table 3-8 gives the estimated hot gas cleanup system capital and maintenance costs. The estimated cost of electricity from the PFBC plants using the alternative cleanup systems is given in Table 3-9. This also shows the recommendations for further development based on a survey of

participants in the study. A breakdown of the capital cost elements for each device is shown in Figure 3-21.

Although this evaluation gives a good assessment of the technologies for PFBC applications, but it may not be directly comparable to IGCC applications. The high recommendations given to electrostatic precipitators is a good example of this.

3210 CONCLUSION

It is concluded that the two most promising developments for particulate cleanup are as follows:

Ceramic cross flow filters:

Good collection efficiency, high volumetric throughput per unit volume, efficient back cleaning. Delamination of elements still has to be resolved.

Ceramic fabric bag filters:

Good collection efficiencies, easy cleaning by pressure pulse, extension of conventional cleanup technology. Some problems with pinholes and possible material degradation in reducing atmospheres.

Electrostatic precipitators, while in theory offering good performance, are likely to require considerable development because of the corrosive gases and the presence of char particles. They have the additional disadvantage of requiring a large pressure vessel for a given volume of gas.

3.3 DESULPHURIZATION

331 GENERAL

The desulphurization of hot gas streams is a very important part of hot gas cleanup. This applies mainly to gasification gas streams and direct coal fired systems as the use of PFBC systems offers the ability to remove the sulphur in the bed by the use of calcium based sorbents as in the case of atmospheric FBC technology.

Gasification fuel gases, being highly reducing, react with a range of oxides to remove the hydrogen sulphide. Materials being researched for this application include zinc ferrite, mixed metal oxides such as cobalt, copper or zinc, and molten alkali metal carbonates. These systems operate at different operating temperatures and offer a range of collection efficiencies. They are also at different development stages.

While not being strictly a hot gas desulphurization technique, the use of in-bed calcium based sorbents in fluid bed gasifiers has had very good results and this work is being extended to fixed and entrained flow gasifiers to evaluate the potential of in situ capture in these processes.

This part of the report reviews work in these areas and evaluates the potential impacts on plant costs and operability.

332 CALCIUM BASED SORBENTS

Calcium based sorbents can be applied to in-bed and external cleanup systems for gasification processes. Limestone or dolomite offer a

low cost material with good adsorption characteristics and provide a basis for an economic desulphurization system based on throw-away sorbents.

.1 In-Bed Desulphurization

In-bed desulphurization is being developed by KRW Energy Systems in its fluid bed gasifier. The objective is to be able to produce a hot, clean, product gas which can be used directly in a gas turbine after removal of the particulate material. The advantage of this approach is that a cheap sorbent can be used and disposed of after use (120).

In the KRW gasifier, the sorbent (limestone or dolomite) is added into the gasifier along with the coal, as shown in Figure 3-22. The calcium carbonate is first calcined, and CO_2 evolved, before the CaO reacts with the H_2S to form CaS. Up to 95% sulphur capture can be attained. Some recent results are shown in Table 3-10 and demonstrate that removal to NSPS quality is possible using in-bed desulphurization alone.

The primary factors affecting desulphurization include bed sorbent concentration, sulphur input rate and sorbent particle size. The Ca/S mole ratio and the gas residence time are of secondary importance. The sorbent type has little effect, unlike the case of bubbling fluid bed boilers. The bed temperature for optimum operation is around 1000°C.

The use of sorbent injection into the gasifier has two further effects. The quantity of ammonia in the product gas has been observed to be reduced by up to 90% depending on feed coal and sorbent type. As the ammonia in the gas is a primary source of NOx, this factor is of considerable importance in reducing emissions. The sorbent is also claimed to reduce the rate of fines elutriation from the gasifier by more than 50%. This may have beneficial impacts on the need for particulate removal downstream.

The performance of the KRW fluid bed gasifier is still being tested. Of interest in this regard is a proposal to test a low sulphur or Alberta plains coal during 1987.

.2 External Desulphurization

Westinghouse is conducting a project for METC to test and evaluate the performance of calcium-based sorbents for sulphur control in direct coal fired turbines at temperatures up to 1200°C. Two external desulphurization concepts are being investigated: coarse-particle fluidized beds and fine-particle entrained beds (99).

Previous work on atmospheric fluidized beds has shown that the optimum temperature for sulphur capture is around 840°C. With pressurized fluid beds operating at pressures of up to 2 MPa, this temperature has been shown to rise to 1000°C. Temperatures higher than this have not been explored, but there is theoretical evidence that calcium-based sorbents are capable of meeting NSPS standards at temperatures as high as 1200 to 1300°C.

The Westinghouse project is aimed at characterizing the two external desulphurizer concepts by obtaining kinetic data on coarse particles from a pressurized, high-temperature thermogravimetric balance. Kinetic data on fine particles are being obtained in a pressurized entrained bed reactor. These data will be used to evaluate the performance of these systems for use in direct coal-fired turbines at temperatures up to 1200°C.

Test results reported so far are restricted to the coarse particle tests. Results show a considerable variability in sulphation performance for the different limestones tested. The effects of particle size show that the smaller sizes exhibit less reduction in rate with increased sulphation than do the larger particles. The effect of temperature varies: some sorbents show little variation, some are activated by higher temperatures.

The results have been used to evaluate the performance of a fluidized bed desulphurizer at temperatures up to 1200°C. Sample results are shown in Table 3-11 for a bed having one second gas residence time. The bed achieves 90% sulphur removal at 1 MPa. This shows that desulphurization at up to 1200°C is feasible, but careful sorbent selection must be conducted. This contrasts with the experience of KRW, reported above, where for in-bed desulphurization, sorbent type appears to have little influence.

Work on entrained bed desulphurization is continuing at Westinghouse and completion is expected by early 1987.

333 ZINC FERRITE PROCESS

The zinc ferrite process has been developed for several years by METC for fuel cell and IGCC applications. The compound zinc ferrite ($ZnFe_2O_4$) is formed by heating a mixture of zinc and iron oxides. It combines the high sulphur affinity of zinc oxide with the good regenerability of iron oxide. Regeneration is carried out by roasting with air or oxygen, using steam to moderate the temperatures which result from the exothermic reactions (115). The resulting SO_2 gas stream can then be passed to a conventional sulphur removal process to extract the sulphur.

After lab-scale and side-stream studies were carried out on 50 mm and 150 mm reactors, tests are now being carried out at the KRW Energy Systems process development unit at Waltz Mill, Pa. The absorption vessel has an inside diameter of 1.5 m and a length of 4.9 m. It is sized on the basis of a 200 hour cycle time at 25% sorbent capacity. Space velocities used range from 280 to 1000 Hr^{-1}. The depth of the bed is varied to provide the capacity required for a particular test. Zinc ferrite pellets from two manufacturers, United Catalyst Inc. and Amax Corp., are being tested.

It has been found that the zinc ferrite is capable of removing sulphur compounds in the gas stream to the 10 ppmw level at temperatures up to 650°C. The process development unit tests are aimed at characterizing the performance and demonstrating reliable system operation for complete removal (fuel cell applications) and polishing (IGCC applications). Up to 90 regeneration cycles have been demonstrated in the laboratory.

The fundamental chemistry of the reactions is shown in Figure 3-23. In addition to the sulphidation reactions, the COS in the fuel gas reacts with water vapour in the gas to give H_2S and CO_2. This, and the CO-H_2 shift reaction, results in the conversion of much of the CO and H_2O in the fuel gas to CO_2 and hydrogen. While this does not significantly affect the overall heating value of the gas, it does result in an improvement in the flame stability because of the additional hydrogen content.

The spent sorbent can be regenerated by steam or oxygen containing gas with SO_2 being evolved. Tests have shown that steam regeneration proceeds at one-tenth of the rate of oxygen regeneration at 2 % by volume. In the KRW gasifier process, the gases produced during regeneration are routed back to the gasifier where they are captured by the limestone sorbent. For application to other gasifiers, the regeneration gas would be handled by a conventional acid gas treatment plant and the sulphur recovered.

To support the work being carried out by KRW, SRI International carried out an evaluation of the solid phase boundaries to delineate the conditions required in the desulphurization reactions to avoid the formation of unwanted solid phases. These phases could significantly affect the ability of the sorbent to be regenerated over many cycles by changing characteristics such as porosity and shape. Phases to be avoided include those with different densities, which evolve large amounts of heat too

rapidly during regeneration, or occlude the sorbent surface during desulphurization. Metallic iron, wustite (FeO), iron carbide (Fe_3C) and carbon should be avoided (109).

The research resulted in the derivation of solid phase stability diagrams at a range of temperatures and pressures. A typical diagram is shown in Figure 3-24 and shows the ratios of atomic carbon, hydrogen and oxygen to be maintained to avoid the unwanted products. In practise, steam is injected to maintain the proper conditions in the desulphurization vessel. In the work being done by KRW, the amount of steam injected has ranged initially from about 0.35 kg/kg gas down to 0.114 kg/kg gas as more experience is gained. It may be possible to use the steam injection to achieve the cooling required between the gasifier outlet and inlet to the zinc ferrite bed.

The zinc ferrite has a theoretical sulphur loading capacity of about 35%. Tests have demonstrated loadings up to 30%. Sampling in the sorbent bed has shown that sharp radial temperature and sulphur loading gradients exist, with the highest temperatures and lower sulphur loadings occurring close to the centerline.

Assessment of the ability of the zinc ferrite to polish low sulphur content gases (in the 1000 ppmw range) has still to be done, as does work on determining the effect of fines on pressure drop across the bed over many cycles. The affect of regeneration on fines in the bed will be investigated to ascertain whether there is any net build-up over a large number of cycles. The formation of soot is another factor to be investigated. Work completed to date on the zinc ferrite test unit has demonstrated that high levels of desulphurization can be achieved. The system has proven easy to operate and control. None of the undesirable phases such as carbon, wustite or carbide has been detected so far.

334 SOLID SUPPORTED MOLTEN SALT PROCESS

This process has been developed by Battelle, Pacific Northwest Laboratories, for use in IGCC and fuel cell applications. The process utilizes the reversible reaction of H_2S with a mixture of molten alkali carbonates. It was first developed based on continuous, countercurrent gas liquid contacting but the hot corrosive molten carbonates led to severe equipment problems and the operation of the process development unit could not be sustained for more than a few hours at a time (31).

The solid supported molten salt (SSMS) concept was developed as an alternative, more practical means of handling the corrosive molten carbonates. This concept uses the pores of a ceramic substrate, lithium aluminate, to hold the molten carbonate. Sulphidation and regeneration are both carried out at high temperature and pressure. Residual sulphur in the cleaned gas is less than 5 ppmw. Regeneration is carried out with a mixture of air, steam, hydrogen and carbon dioxide (34) and produces a H_2S rich gas containing up to 50% H_2S from which sulphur is extracted. It was found that hydrogen or carbon monoxide had to be included in the regeneration gases to avoid leaving traces of oxidized sulphur in the bed which would be reduced during subsequent adsorption and contaminate the product gas.

Bench scale tests have been carried out which show that the process will remove H_2S and COS simultaneously at a temperature of approximately 800°C and a pressure of 1.24 MPa. Removal of H_2S to less than 1 ppmw was established over 16 cycles of regeneration. Space velocities of 300 to 2300 Hr^{-1} were used in tests.

An engineering process design and cost estimation study has been carried out to design a cleanup system based on the experimental results and incorporating commercial technology to recover the sulphur. The net calculated power generation efficiency was 45.6% for a integrated gasification molten carbonate fuel cell application.

335 MIXED METAL OXIDES PROCESS

Considerable work has been carried out in the US in recent years on the use of a variety of metal oxides as sorbents for hot gas desulphurization. Much of this work has been sponsored by METC and is still in the conceptual proof-of-concept stage. Oxides evaluated have included CuO/ZnO (61), ZnO-V_2O_5/Al_2O_3 and ZnO-Fe_2O_3 (59), ZnO-Co_2TiO_4 (58) and Zn-Fe-O and Cu-Fe-O (33). The major efforts are now concentrated in work being carried out by the Institute of Gas Technology and the California Institute of Technology.

The Institute of Gas Technology (IGT) is involved in a program to develop and evaluate means of reducing sulphur containing compounds and HCl from coal-derived fuel gases. As this is being carried out with fuel cell applications in mind, the goal is to remove these compounds to a level of less than 1 ppmw at an operating temperature between 540 and 760°C. The concept of mixed metal oxides is being considered for this application. In this process, sulphur containing compounds are removed from the hot gas by reaction with a mixture of metal oxide containing sorbents.

Typical reactions are:

$$MO + H_2S \rightarrow MS + H_2O$$
$$MO + COS \rightarrow MS + CO_2$$

MO symbolizes the mixed metal oxide sorbent and MS the corresponding sulphide. The mixture contains two types of oxides: a low-affinity oxide which can remove only about 70% of the sulphur content of the gas because of chemical thermodynamic limitations, and a high affinity oxide which can reduce the remaining sulphur content of the fuel gas to very low levels. The reason for using this mixture is that during regeneration with an oxygen containing gas, the process produces elemental sulphur as a by-product. A schematic of the reaction during adsorption and regeneration is shown in Figure 3-25.

For the past several years, work at IGT has been centered on defining the appropriate low-affinity metal oxide to use with the process, which is the key to elemental sulphur production. Many candidate materials have been evaluated against the criteria of sulphur removal, sulphur production and structural stability. Table 3-12 shows the range of materials tested, leading to the conclusion that only cobalt titanate provided the required performance.

Bench-scale tests have been carried out using a 90% cobalt titanate - 10% zinc oxide mixture which was sulphided and regenerated eleven times. Sulphation was performed with a simulated fuel gas at temperatures ranging from 650 to 815°C and atmospheric pressure. Regeneration was conducted at various initial bed temperatures from 650 to 900°C. Tests demonstrated the technical viability of the process, but pointed out the need to optimize the cobalt titantate sorbent to reduce the costs of the process. This will also result in the production of elemental sulphur during regeneration.

A range of tests are planned using sorbents containing varying proportions of cobalt titanate and titanium dioxide. The tests will be conducted at 1.7 MPa pressure and 650°C. The tests will be used to estimate process performance at a larger scale and for planning bench-scale studies. A bench-scale test unit is being designed to provide particulate, sulphur and HCl cleanup cababilities for gasifier gas streams. The test unit design parameters are shown in Table 3-13. Testing with this unit was expected to begin early in 1987.

Work at the California Institute of Technology (CalTech) has also been aimed at fuel cell applications. Two classes of sorbents were examined. One consists of eutectic mixtures of metal oxides, such as $ZnO-V_2O_5$ and $CuO-MoO_3$, in the form of a melt coating the pore surface of a solid support. The other class includes unsupported mixed oxides in the form of solid solutions of solid compounds, such as Zn-Fe-O, Cu-Fe-O,

Cu-Fe-Al-O and Cu-Mo-Al-O. Both classes of sorbents exhibit rapid kinetics of absorption, high absorption capacity and good regenerability (33).

This work has shown that the second class of oxide solid solutions demonstrated greatly improved sorbent utilization and performance stability over conventional sorbents. Additional efforts are now being made to optimize selection of sorbents oxide mixtures by conducting a range of experiments with the various mixtures of oxides at atmospheric pressure and a temperature of 650°C. Following these tests, a simulated KRW gasifier product gas will be used in sulphidation runs with selected sorbent compositions at temperatures in the 650 to 800°C range (113).

336 IRON OXIDE PROCESS

Iron oxide based sorbents can provide good performance in hot gas cleanup systems at temperatures up to 450 to 500°C. Although a number of developers have carried out work on iron oxide processes (88), only the CMRC in Japan has developed the process to the PDU stage (123, 124).

CMRC has a 40 t/d fluid bed gasifier PDU in operation at Yubari, Hokkaido. This unit has a hot gas cleanup system comprising a moving bed particulate filter and an iron oxide desulphurizer. A schematic of the system in shown in Figure 3-26. The system is designed to clean 4500 Nm^3/hr of gas at a temperature around 450°C and at pressures of up to 2 MPa. The desulphurizer consists of a fluid bed absorber containing iron oxide as iron ore which is converted to iron sulphide in removing the sulphur gases from the fuel gas. The spent sorbent is transferred to the fluid bed regenerator where it is converted back to iron oxide by air blowing. The air removes the sulphur as sulphur dioxide which is reduced to elemental sulphur in an anthracite bed.

Initial operating problems due to tar condensation and corrosion and erosion damage to valves and flanges were experienced. Once these were overcome, tests totalling almost 400 hours running time were carried out using iron ore as a sorbent. The coal used was a local low sulphur Taiheiyo giving low levels of sulphur compounds in the fuel gas. Additions of sulphur were made to give levels in the 500 to 2600 ppmw in the fuel gas. The temperature in the absorber bed was varied between 420 and 480°C at pressures between 1.5 and 1.8 MPa. Minimum desulphurization attained was 91%, with an average close to the design value of around 95%.

During runs with silica carried iron oxide as a sorbent, very low efficiencies were attained. This was thought to be caused by the differences in the densities between this sorbent and that of iron ore causing abnormal fluidization in the adsorber vessel. Run times attained have been rather short and further modifications have been carried out to improve the availability of the system as a whole. No specific research results have been obtained for the more recent work carried out. During a visit made to this facility in the fall of 1986 as part of a coal gasification study, the desulphurizer was not in operation and was undergoing major modifications.

337 EVALUATION

Hot gas desulphurization systems have not been developed to the point where published capital and operating cost information is generally available. For most of the systems covered in previous parts of this report, testing has been limited to laboratory scale. This evaluation is therefore limited to a general discussion of the status of the processes under development. A summary of the processes under development is given in Table 3-14.

A METC study in progress (115) has, as its objective, the evaluation of hot desulphurization processes in IGCC and fuel cell power plants. This study will provide conceptual designs, cost and economic information. Unfortunately, only the results for fuel cell power plants are available at the time of writing.

For the fuel cell application, a total of eleven cases were studied, using a range of fixed bed, fluid bed and entrained flow gasifiers. The desulphurization systems consisted of the METC zinc ferrite, the Battelle solid-supported molten salt, and the Institute of Gas Technology mixed metal oxide process. The cases considered are given in Table 3-15. Following conceptual design, costs and economics were evaluated. The results are summarized in Table 3-16 and show that the METC zinc ferrite process had the lowest total levelized cost of electricity for all cases.

The desulphurization processes reviewed have a range of sulphur capture efficiencies and operating temperatures. Figure 3-27 gives an overview of the performance to be expected of the processes. From this it can be seen that the iron oxide process is barely able to meet the NSPS requirements. Calcium sorbents provide a satisfactory removal level and external beds are capable of operation at temperatures up to 1100°C.

At the present stage of development, none of the processes can be said to be developed to the point of commercialization. In most cases, testing has not yet fully explored the performance of the sorbents in terms of capture performance under realistic conditions representative of full scale operation. A major concern is the ability of the sorbent to be regenerated over a large number of cycles without losing its adsorption capacity. There is also a possibility that the sorbent will break up during cycling and the dust produced entrained in the gas stream at a point downstream of the particulate cleanup equipment.

A general concern with regenerating sorbents is the requirement to divert and control hot gas streams by means of valves. Sudden warmup of refractory coated vessels and piping should be avoided due to the risk of damage caused by moisure suddenly evaporating. The problem of developing suitable valves to give a tight shut off should not be underestimated, particularly in view of the reduction atmosphere which prevails in these applications. For this reason, the KRW in-bed system has a particular advantage.

338 CONCLUSIONS

It can be concluded that a number of different processes are under development which will offer removal efficiencies in excess of that required for NSPS standards. At this time, none of these can be considered as commercial.

Calcium based systems, both in-bed and external, have considerable promise. The KRW fluid bed gasifier with calcium based sorbent appears the most likely of the processes to achieve commercial status. Although this process avoids the problems of regeneration of the sorbent, there is still the need to dispose of considerable quantities of spent sorbent. This has first to be oxidized to a sulphate prior to disposal. Calcium based systems may also be applicable to other gasifiers by means of external beds, fixed or fluid.

More advanced processes, while offering the very high capture efficiencies required for fuel cell applications, are at an early stage of development and cannot be considered as potential cleanup methods until futher work is carried out at a larger scale.

3.4 ALKALI METALS

341 GENERAL

The control of alkalis in hot gas streams is made more complex because of two factors. Firstly, there is no clearly established standard for allowable levels of alkali in the gas stream to the turbine. Conventionally, the level is established by a comparison with the standard for alkali content in liquid turbine fuels (0.5 to 5 ppmw) (92). This corresponds to a level of 0.05 to 0.5 ppmw in low heating value gas. However, there is good evidence that the forms of alkali in coal derived gases do not have the same effects as those from liquid fuels and that alkali may be less of a problem in coal gases (91).

The other major problem is that the low levels of alkali in the coal gas are extremely difficult to detect and accurately measure. Much attention has been focussed on the problem of determination of total and vapour-phase alkali. DOE/METC have developed a spectrometer which can detect alkalis at the parts-per-billion levels.

Much of the cleanup process development is based on the premise that vapour-phase alkali species will condense on particulates and be captured by particulate removal devices at temperatures below 650°C. There is some evidence to support this, but additional work is required to establish the lower temperature limit for significant alkali vapourization and whether this is dependent on coal type (91).

A number of projects underway in the U.S. are being supported by the DOE at METC. These are directed at PFBC and coal gasification use sorbents such as activated bauxite and emathlite.

342 FIXED BED PROCESSES

Two fixed bed processes are being developed in the U.S. by Westinghouse and Argonne National Laboratory, with DOE/METC funding. These are aimed at gasification and PFBC applications and are described below.

The Argonne National Laboratory is developing an activated bauxite sorbent to remove alkali material from PFBC gas streams (4). Alkali vapour concentrations in PFBC gas streams have been measured in the range of 0.1 to 10 ppmw, and are principally composed of sodium and potassium sulphate in the condensed phase. Activated bauxite has been found to be effective in capturing the NaCl, KCl and K_2SO_4 vapours which were doped into simulated PFBC gas streams. It has also been demonstrated that the bauxite can be regenerated for reuse by water washing. A capture efficiency of greater than 99.8% NaCl-vapour has been achieved. The bauxite is composed of 81.5% of Al_2O_3, 10% SiO_3, 3% Fe_2O_3 and other minor components. Test conditions were 800°C and 1 MPa, using a simulated PFBC atmosphere doped with 4 to 12 ppmw NaCl vapour.

A laboratory scale alkali sorber has been developed for use with the Argonne laboratory scale PFBC and is shown in Figure 3-28. This unit contains both secondary particulate cleaner cyclones and alkali sorber. Test runs were carried out at temperatures between 850°C and 900°C. Measurements of alkali levels in the raw gas stream have been made but evaluation of the sorber performance is still in progress and no results are available.

Westinghouse has been investigating the use of emathlite, a naturally occuring clay, as a getter since 1978 (92). It has been determined that this is an effective alkali remover when used in pellet form in a fixed bed. Investigations have been carried out at bench-scale and have shown that 10 ppmw of NaCl in a feed stream can be reduced by 80%. In this process, the emathlite reacts irreversibly with the alkali and the concept is that the bed material is replaced annually.

Test units used in this work have operated at 1.1 MPa and temperatures between 800°C and 900°C (95). Based on this research, emathlite was identified as a leading getter material due to its low cost, high sodium capacity and irreversible capture of sodium. This occurs by the formation of a glass from gaseous sodium and the silica in the emathlite. The glass is predominantly $Na_2Si_2O_5$.

A bench-scale process development unit has been used to test pellets of varying size. This is shown in Figure 3-29, and has been used to identify a commercial pelletization process. Work is now being carried out to evaluate the performance of the bed in gasifier conditions.

343 ADDITIVES

The concept of capturing undesirable alkali components in the gas stream by the use of additives is being investigated by two contractors with DOE/METC funding. This has applications to the control of alkali metals, trace metals and aromatic hydrocarbons in pulverized coal flames. The process being considered is the adsorption of the undesirable components onto the surface of a solid collector, such as activated alumina, which is directly injected into the flame.

The University of Pittsburgh is carrying out a research program which will investigate candidate collector materials which will be injected into pulverized coal flames, collected from the flue gases and analysed. The combustion conditions will be varied to provide a range of oxidizing and reducing conditions, temperatures and residence times to simulate a range of gasifier and combustor conditions.

A combustion system has been designed, constructed and tested. A variety of aluminas and other candidate materials have been tested using a high sodium content North Dakota lignite. Combustor conditions

covered a range of temperatures from 800°C to 1000°C and excess air levels of -33% to +266%. This gave a range of oxidizing and reducing conditions resulting in a variety of chemical species being liberated. Results of these tests have indicated that porous glass had the highest collection of sodium.

Future work will examine a range of different types of porous glasses under appropriate combustor conditions. Lower temperatures yield higher collection of sodium for some of the sorbents and this will be further examined.

The University of Arizona is carrying out a research program to determine the effects of process temperature profiles of coal/additive mixtures on the alkali and trace metal content of ash particles formed during high temperature entrained flow gasification and combustion of pulverized coal. The work is based on the concept that control of temperature and quench rate can influence the fraction of volatile alkali and trace metals condensing on fly ash particles. Additives considered include kaolinite and powdered limestone (45).

The work will be carried out on a downward firing plane flame reactor modified to allow trapping and classifying fly ash particles. A schematic of this is shown in Figure 3-30. Tests will be carried out under fuel rich and fuel lean conditions to simulate gasification and combustion conditions. Each size range of ash particle collected will be analysed for alkali and trace metal content. Tests will be carried out with bituminous coal and lignite.

After base conditions have been established, the effects of varying temperature gradients and by the addition of kaolinite and powered limestone on the amount of alkali capture in the fly ash will be investigated. At the time of writing, no results were available from this research.

344 EVALUATION

Alkali metal removal processes are still at an early stage of development. As in the case of desulphurization processes, there is no published information available on the projected costs and economics of systems.

The fixed bed processes are at a more developed stage. Development to the pilot scale is likely to be hindered by the lack of definition of cleanup requirements for this pollutant and by the difficulties in measurement of the low levels which exist in gasifier gas streams.

There is still considerable disagreement among workers in the field as to what the extent of the alkali problem is likely to be. A view held by some is that coal derived gases are not as much of a problem as liquid fuels. There is also some evidence to support the view that much of the alkali in the gas stream will be removed in the particulate cleanup stage by condensation on to the dust particles.

345 CONCLUSION

A number of processes have been demonstrated in principle and show that high levels of alkali capture are possible. Considerable development work is required before they can be considered as commercial processes. Before this can be done, actual cleanup needs will have to be more closely defined.

3.5 HYDROGEN CHLORIDE

351 GENERAL

The requirement for hydrogen chloride removal from coal derived fuel gases has not been defined for applications other than fuel cells. For this application a level of from 0.1 to 10 ppmw has been established (92). Other applications involving gas turbines are not expected to be as stringent, although chloride levels specified by gas turbine manufacturers for liquid fuels are shown in Table 1-1 to be in the 1 ppmw range. The concentration of chloride species in coal gas has been found to be in the range of 1 to 500 ppmw (17).

A number of processes are available for the removal of HCl vapour from industrial and incinerator waste gases. These involve the adsorption of the HCl onto activated carbon or alumina or by reaction with alkali. However, the sorbents used are designed to operate below 450°C and are not economically regenerable.

DOE/METC has sponsored a number of projects to develop processes to remove HCl to below 1 ppmw. These use fixed bed reactors and solid supported molten salts. In the latter case, the HCl removal capability is in addition to the desulphurization carried out at the same time.

352 FIXED BED PROCESSES

Physical Sciences Inc. carried out a screening study for DOE/METC to screen and test potential hot gas chloride sorbents for possible use in a hot gas cleanup process in a fuel cell IGCC power plant (62). The aim was to reduce chloride levels to the 1 ppmw range. The search concentrated on economical, naturally occurring mineral sorbents containing alkali.

The results of the screening process showed that alkali carbonates are the only substances that can reduce the chloride concentration below parts per million levels at temperatures up to 525°C. It was also shown that above this temperature the chloride concentration cannot be reduced below parts per million levels at equilibrium. The tests showed that the mineral shortite ($Na_2Ca_2(CO_3)_3$) is a leading candidate as a chloride sorbent.

Following this work, SRI International evaluated three sorbents for use in removing hydrogen chloride vapour from coal gas streams at a temperature range of 523°C to 623°C (17, 46, 97). The program tasks included sorbent reactivity determination, bench scale studies, and preliminary system configuration evaluation. HCL concentrations ranged from 10 to 300 ppm.

Two naturally occuring minerals, shortite and nahcolite ($NaHCO_3$), were selected along with a commercial sorbent, Katalco Chloride Guard catalyst. This sorbent is designed for use in the removal of chloride from natural gas and light hydrocarbon feedstocks. It is used to remove chloride (10 ppmw) from process streams in a temperature range of 150°C to 450°C.

The reactivity of the sorbents was tested by exposing the sorbent in a fixed bed to a simulated coal gas containing 100 to 500 ppm of HCl. All the sorbents reacted rapidly with the HCl to give an initial exit gas concentration of around 1 ppmw. This exit gas concentration increased with time. Under similar conditions, the time for 1 ppmw breakthrough was progressively greater for shortite, Katalco Guard and nahcolite. Under the experimental conditions, about 90% of the sodium content of the Katalco Guard could be converted to NaCl at 523°C if steam were not added to the gas stream. The addition of steam reduced the reactivity and capacity of the sorbent. In simulated Texaco gas streams, capacity was reduced to 70%.

Shortite was found to have only about 20% conversion, but nahcolite was found to have about 90% conversion even in the presence of 35% steam. Increasing the temperature above 623°C had only a minor effect on the reactivity (17).

Following on this work, preliminary system configurations were evaluated, assuming either a Texaco oxygen blown or a Lurgi air blown dry bottom gasifier. The HCl removal step was placed downstream from particulate and H_2S removal to take advantage of the reduction in volume resulting from the zinc ferrite desulphurization process. Of the sorbents tested, only the nahcolite offered the advantages of high chloride capacity and low cost for use as a throwaway sorbent. The process selected uses two sorbent beds, with one operating and one reloading with fresh sorbent. The sorbent cycle time varied between 15 days with the Texaco oxygen blown case to 50 days with the Lurgi air blown case.

Capital and operating costs were estimated and the total annual operating costs were evaluated at 0.174 mills/kWh for the Texaco case and 3.07 mills/kWh for the Lurgi case. The cost of the sorbent is a minor component compared with the cost of capital expenses.

353 MOLTEN SALT PROCESSES

Two evaluations have been carried out using molten salts supported by a ceramic substrate to capture chloride in the fuel gas down to parts per million levels. Battelle Pacific Northwest Laboratories' SSMS process described in Part 334 of this report has been used to remove H_2S, COS and HCl from a fuel cell feed gas at temperatures around 800°C and up to 1.24 MPa pressure.

The sorbent used is a molten carbonate which reacts to form chloride. Removal of 200 ppmw HCl to less than 1 ppmw was demonstrated in bench scale experiments. This was only a preliminary evaluation and more work will be required to assess the regeneration of the sorbents (31, 114). One step H_2S, COS and HCl removal was demonstrated, but it appears likely that this will result in a more expensive cleanup system than some other alternatives.

The Institute of Gas Technology has carried out studies on the use of a molten alkali carbonate sorbent supported by a ceramic for high temperature HCl removal. The sorbent used in the studies was composed of a 52% lithium to 48% sodium carbonate mixture using magnesium oxide as the ceramic support and fabricated as 25 mm pellets. In laboratory scale fixed-bed reactor tests, the sorbent removed more than 99.7% of HCl from a gas stream at 600°C and atmospheric pressure. It is assumed that this sorbent would be discarded after use.

Economic studies carried out for this system concluded that the impact on the costs of a fuel cell IGCC plant would be about 5 mills/kWh. This assumes a chloride inlet level of 300 ppmw.

354 EVALUATION

Development of chloride removal systems is at a very preliminary stage. Several processes have been proved in concept and approximate costs have been evaluated for fuel cell IGCC applications. Based on the limited data, the fixed bed process using nahcolite appears to be the most likely candidate for early commercialization, but requires extensive development.

Based on the preliminary cost data, it appears that the cost of chloride removal will be in the range 1 to 5 mills/kWh.

355 CONCLUSION

Although chloride removal processes have been proved in concept, it will be some time before they are available commercially. Preliminary cost information shows that cleanup will add significantly to the cost of electricity.

So far, most work in this area has been directed at fuel cell applications. Allowable chloride levels for gas turbines still have to be defined. It is believed that chlorides from coal derived fuels is not as significant as from liquid fuels.

TABLE 3-1

Results of Ceramic Cross-Flow Filter Testing at METC

Temperature (°C)	Pressure (Bar)	Average Filter Face Velocity (m/s)	Average Inlet Dust Loading (ppmw)	Average Collection Efficiency (Percent)
538	17	0.025	7,975	99.47
649	17	0.015	1,112	99.25
815	17	0.028	2,337	98.44
760	10	0.042	593	98.74
649	10	0.041*	2,408	98.34

* Test conducted on hot nitrogen instead of gasifier fuel gas.

Source: Reference 8

TABLE 3-2

Preliminary Results of METC Ceramic Filter Bag Tests

Test No.	Test Duration (hr)	Temperature (°C)	Pressure (bar)	Filter Face Velocity (m/s)	Average Dust Loading (ppmw)	Average Collection Efficiency (Percent)	Average Outlet Particle Size (Micron)
1	10	649	10	0.015	1,960	99.2	11
2*	50	649	10	0.015	265	94.7	3*
3	50	649	10	0.015	2,400	90.3	12

* Desulphurized gas
Source: Reference 8

TABLE 3-3

EPRI Particulate Cleanup Device Rankings

Rank	Device	Major Advantages	Major Disadvantages	Recommendations
1	Cyclone (rank dependent on enhancement of heat recovery)	1. Commercially proven 2. Economical	Limited efficiency. Probably can't meet fixed-bed reactor requirement.	1. Determine particle density and size distribution at Cool Water 2. Design and cost studies if heat recovery looks favourable 3. Test cyclone and heat recovery at Cool Water if studies are favorable
2	Ceramic candle filter	Excellent dust removal	Limited testing. Durability and cleanability not convincingly demonstrated.	First choice if cyclones not adequate; follow Westinghouse and GE work
3	Fiber filters (tentative rank; confirm in KRW zinc ferrite program	1. Good dust removal (doubtful for use with bed reactors) 2. Extensive commercial experience with related devices	1. Limited data on latest bags. Early bags fragile or not cleanable. 2. Metals in hot raw gas for most forms tested.	Follow KRW zinc ferrite process development
4	Screenless granular bed filter	Operated 5-ft unit with no major problems; no inlet screen to foul or corrode	Limited efficiency: less than fiber filter, greater than cyclones.	Favoured over screened granular bed filters
5	Cross-flow filters	1. Excellent dust removal 2. High surface per unit volume	1. Limited testing. Durability and cleanability not convincingly tested. 2. May require metal contact with hot gas 3. Complex configuration	Follow the development if it is reactivated by DOE or others

Source: Reference 22
Note: Cool Water refers to the IGCC demonstration project (Reference 126).

TABLE 3-4

Hot Gas Cleanup Devices Investigated for
Possible Coal Gasification Use

Device	Developer
Acoustic Agglomerator	Various[1]
Ceramic Baghouse Filter	Acurex
Ceramic Cross-flow Filter	Westinghouse
Dry Plate Scrubber	Air Pollution Technology
Ducon Granular Bed Filter	Westinghouse
Electrostatically-Enhanced Granular Bed Filter	General Electric
Electrostatic Precipitator	Research Cottrell
Electrocyclone	General Electric
Magnetically-Stabilized Bed Filter	Exxon
Screenless Granular Bed Filter	Combustion Power

[1] Acoustic agglomerators for HGCU are being studied by Pennsylvania State University and Aerojet Energy Conversion Company, and were investigated at the State University of New York at Buffalo.

Source: Reference 55

TABLE 3-5

Net Particle Collection Efficiency

Cleanup Device	Fixed Bed Gasifier	Fluidized Bed Gasifier	Entrained Bed Gasifier	Typical PFB
Ceramic Bag filter[1]	99.9	99.9	99.9	99.9
Cylindrical ESP[1]	85.1	99.9	100.0	98.9
Screenless GBF	81.2	99.6	100.0	96.3
Ceramic Cross Flow[1] Filter	99.9	99.9	99.9	99.9
Electrocyclone[1]	24.9	89.2	99.5	71.8
Electrostatic GBF[1]	100.0	99.9	99.8	98.1
Fixed GBF[1]	98.0	98.0	98.0	98.0
Magnetically Stabilized GBF[1]	21.7	84.3	98.4	60.8
Dry Plate Scrubber[2]	96-98	96-98	98.5-99.8	95-96
Acoustic agglomeration/augmented cyclone	50-75	86-97	97-99.5	75-92

Notes:

[1] Values based on performance model simulations.
[2] Values estimated from best available information.
PFB Pulverized fuel boiler.
ESP Electrostatic precipitator.
GBF Granular bed filter.

Source: Reference 55

TABLE 3-6

Current Development Status

Device	PFBC Type	Maximum Flow, m^3/min	Velocity, m/min	Maximum Temp, °C	Maximum Pressure, kPa	Collection Efficiency, %	Test Duration, hrs.
Cottrell Environmental Sciences, ESP	Actual	31	28	865	655	72-99.6	362
	Simulated	4.4	53	900	965	83-98.9	150
Acurex Ceramic Felt Filter	Actual	23	1.5	790	585	99.9	140
	Simulated	14	4.6	815	1140	99.0	77
Westinghouse Ceramic Cross Flow Filter	Actual	0.42	3.8	800	930	99.9	90
	Simulated	0.57	5.2	815	1035	99.99	450
Ducon/Westinghouse Static GBF	Simulated	14	14	845	965	77-99	50
General Electric Electrostatic GBF	Actual	14	15	845	100	70	75
	Simulated	28	12-61	Ambient	100	-	-
Combustion Power Co. Moving GBF	Simulated	46	24	875	100	99.1	200
Air Pollution Tech. Dry Plate Scrubber	Simulated	0.62	19	600	965	70-99.7	0.2
Exxon Magnetic GBF	Actual	1.3	88	880	?	97.5	-
General Electric Electrocyclone	Simulated	97	2560	885	650	93-96	16
Aerojet/PSU Accoustic Agglom.	Simulated	-	-	Ambient	100	-	-

Source: Reference 10

TABLE 3-7

Device Cleanup Efficiencies

Device	As Reported by Contractor	Normalized HGCU System with Standard Operating Conditions, Inlet Distributions and Loadings
Aerojet/PSU AA	81.86[1]	99.96[2]
Acurex Ceramic Felt Filter[3]	99.60	99.98
CPC Moving GBF	99.07	99.93
Exxon Magnetic GBF[3]	97.47	99.92
Westinghouse Ceramic Cross Flow Filter[3]	99.96	99.99
APT Dry Plate Scrubber	96.59	99.58
Ducon/Westinghouse Shallow Static GBF	98.33	99.96
GE Electrostatic GBF[3]	85.98	98.19
GE Electrocyclone	94.3	99.5
CES Electrostatic Precipitator	98.0	99.6

Notes:

1 After passing PFBC outlet flyash through a 6 ft. Stairmand Type High Flow cyclone and a 4 ft Van Tongeren Type High Efficiency cyclone in series.

2 After passing PFBC outlet flyash through the Acoustic Agglomerator, a 6 ft Stairmand Type High Flow cyclone and two 4 ft Van Tongeren Type High Efficiency cyclones in series.

3 Only data point is single total efficiency; a mean inlet particle size was used.

HGCU Hot gas cleanup.
AA Acoustic agglomerator.
GBF Granular bed filter.
APT Air Pollution Technology.
GE General Electric.
CES Cottrell Environmental Sciences.

Source: Reference 10

TABLE 3-8

Hot Gas Cleanup Estimated Capital and Maintenance Costs

Title	Total HGCU System Capital Cost		Total Annual Maintenance Cost	
	$ x 10^3	$/kW	$ x 10^3	$/kW
Baseline PFBC Multicyclone	124,200	188	4,963	7.5
Electrostatic Precipitator (CES)	125,500	189	6,728	10.2
Ceramic Felt Filter (Acurex Corp.)	190,400	288	9,342	14.1
Ceramic Cross Flow Filter (Westinghouse)	78,200	117	4,862	7.4
Shallow Static GBF (Ducon/Westinghouse)	120,300	180	6,345	9.6
Moving GBF (CPC)	120,500	181	4,472	6.8
Electrostatic GBF (GE)	97,100	146	4,535	6.9
Dry Plate Scrubber (APT)	191,500	292	11,633	17.6
Magnetic GBF (Exxon)	189,100	293	5,440	8.2
Electrocyclone (GE)	116,200	176	5,066	7.7
Acoustic Agglomerator (Aerojet/PSU)	104,400	155	4,635	7.0

Source: Reference 10

TABLE 3-9

Cost of Electricity Summary
(Costs in Mills/kWh - 1983 dollars)

Plant	COE	% Change from Base	No. of Recommendations
Conventional Coal Fired	105	+6	-
Baseline ..BC Multicyclone	99	0	-
CES Electrostatic Precipitator	101	+2	21
Acurex Ceramic Felt Filter	105	+6	9
Westinghouse Ceramic Cross Flow	96	-3	13
Ducon/Westinghouse Shallow Static GBF	99	0	1
CPC Moving Bed GBF	98	-1	14
GE Electrostatic GBF	98	-1	2
APT Dry Plate Scrubber	108	+9	0
Exxon Magnetic GBF	107	+8	0
GE Electrocyclone	100	+1	2
Aerojet/PSU Acoustic Agglomerator	98	-1	6

Source: Reference 10

TABLES 3-10

KRW Sulphur Removal Results

Parameter	Test Data				
Coal Type	Pgh, #8	Pgh, #8	Wyoming	Pgh. #8	Pgh. #8
Coal Sulphur, %	2.3	2.3	2.0	4.5	4.5
Sorbent Type	None	Dolomite	Dolomite	Limestone	Limestone
Ca/S, Molar Feed	-	1.7	2.0	2.0	1.9
Desulphurization, %	10	86	87	91	89
NSPS Requirement, %	83	83	84	90	90

Note: 95% desulphurization has been achieved with limestone sorbent in recent PDU tests.
Resource: Reference 120

TABLE 3-11

Fluidized Bed Sulphur Removal Performance

Sorbent	Calcium-to-sulphur Ratio [Sorbent over Sulphur Mass]			
Particle average Diameter Microns)	387	1095	387	1095
Temperature (°C)	1000		1200	
Tymochtee Dolomite	0.92 [5.7]	0.97 [6.0]	1.4 [8.5]	1.6 [9.8]
Plum Run Dolomite	0.92 [5.8]	0.96 [6.0]	1.7 [10.5]	2.0 [12.1]
Highland Limestone	1.6 [5.8]	1.9 [7.0]	1.5 [5.6]	2.1 [7.9]
Greer Limestone	2.9 [9.5]	3.7 [12.2]	3.8 [12.7]	4.4 [14.6]
Carbon Limestone	1.7 [6.1]	3.3 [11.7]	1.8 [6.5]	2.1 [7.4]
Mississippi Limestone	2.2 [7.1]	2.6 [8.4]	3.3 [11.0]	3.6 [11.8]
Vicron Limestone	3.1 [10.3]	3.8 [12.6]	4.1 [13.5]	4.5 [14.8]

Source: Reference 99

TABLE 3-12

Low Affinity Oxides Evaluated by IGT

Oxide	Sulphur Removal	Sulphur Production	Structural Stability
$ZnAl_2O_4$		X	X
$ZnCr_2O_4$		X	X
Cr_2O_3		X	X
$CuCr_2O_4$	X		
CoO/SiO	X		X
MnO	X		
$FeCr_2O_4$	X	X	
Fe_2SiO_4	X	X	
$CoTiO_3$	X	X	X

X = Acceptable performance

Source: Reference 112

TABLE 3-13

Bench-Scale Unit Description

Item	Value
Gas Handling Capacity	300 to 3000 SCF/h
Pressure Rating	300 psig and 1400°F
Maximum Sorbent Bed Temperature	1800°F
Particulate Removal System	Four 60-mm 0 x 1 m Silicon Carbide Candles
Hot Gas Desulphurization System	1 ft^3 Sorbent Capacity 8 TC's for Temperature Profile Glycol Elemental Sulphur Collection System
Hot Gas HCl Removal System	Two 0.3-ft^3 Sorbent Compartments Gas Sampling Between Beds

Source: Reference 112

TABLE 3-14

Desulphurization Evaluation

Process	Developer	Status	Sulphur Capture %	Performance Pressure MPa	Temp Deg.C	Applications
Calcium based:	KRW	PDU	Up to 95%	3	1000	IGCC
In bed	Westinghouse	Laboratory	90%	1	1200	IGCC
External						
Zinc Ferrite	METC/KRW	PDU	To 10 ppmw	1.6	650	Fuel cells or IGCC
SSMS	Battelle Pacific	Laboratory	To 1 ppmw	1.24	800	Fuel cells
Mixed metal oxides	IGT	Bench-scale	To 1 ppmw	Atmospheric	800	Fuel cells
Iron Oxide	CMRC	PDU	90%	2	450	IGCC

TABLE 3-15

Summary of Hot Gas Cleanup Cases

Case	Sorbent Process				
METC[1]	Battelle[2]	IGT[3]	Gasifier	Hot Gas Cleanup Reactor	Sulphide Sorbent Regenerator
1	6	9	Air-Fixed-Bed Dry Ash	Fixed	Fixed
2	7	10	O_2-Texaco-Quench	Fixed	Fixed
3	8	11	O_2-KRW Fluid-Bed	Fixed	Fixed
4			O_2-KRW Fluid-Bed	Fluid	Fluid
5			O_2-Fixed-Bed Dry Ash	Fixed	Fixed

[1] Zinc Ferrite
[2] Solid-Supported Molten Salt
[3] Mixed Metal Oxides

Source: Reference 115

TABLE 3-16

Summary of Costs

Case No.	Removal System/Gasifier/Sulphur Recovery	TPC ($/kW)[1]	COE (Mills/kWh)[2]	Cost/Sulphur ($/ton-yr)[3]
1a	METC - Fixed Bed/Lurgi - Air/Dual Alkali Scrubber	333	25.9	2,445
1b	METC - Fixed Bed/Lurgi - Air/Wellman - Lord/Allied	474	28.5	2,649
2a	METC - Fixed Bed/Texaco - O_2/Dual Alkali Scrubber	263	22.2	2,301
2b	METC - Fixed Bed/Texaco - O_2/Dual Alkali Scrubber	374	23.9	2,440
3a	METC - Fixed Bed/KRW - O_2/Dual Alkali Scrubber	265	22.8	2,330
3b	METC - Fixed Bed/KRW - O_2/Wellman - Lord Allied	377	24.5	2,469
4a	METC - Fluid Bed/KRW - O_2/Dual Alkali Scrubber	233	29.7	3,022
4b	METC - Fluid Bed/KRW - O_2/Wellman - Lord/Allied	345	31.4	3,144
5a	METC - Fixed Bed/Lurgi - O_2/Dual Alkali Scrubber	344	29.0	2,529
5b	METC - Fixed Bed/Lurgi - O_2/Wellman - Lord/Allied	484	31.4	2,688
6	Battelle/Lurgi - Air/Stretford	652	161.6	12,688
7	Battelle/Texaco - O_2/Stretford	396	50.1	4,569
8	Battelle/KRW - O_2/Stretford	378	31.3	2,801
9	IGT/Lurgi - Air/IGT	494	56.4	4,797
10	IGT/Texaco - O_2/IGT	247	33.1	3,211
11	IGT/KRW - O_2/IGT	220	31.9	2,984

1 TPC - Total desulphurizationn plant cost - 1985 (December) - $U.S.
2 30 year levelized cost of electricity
3 Cost per ton of sulphur removed per year
Source: Reference 115

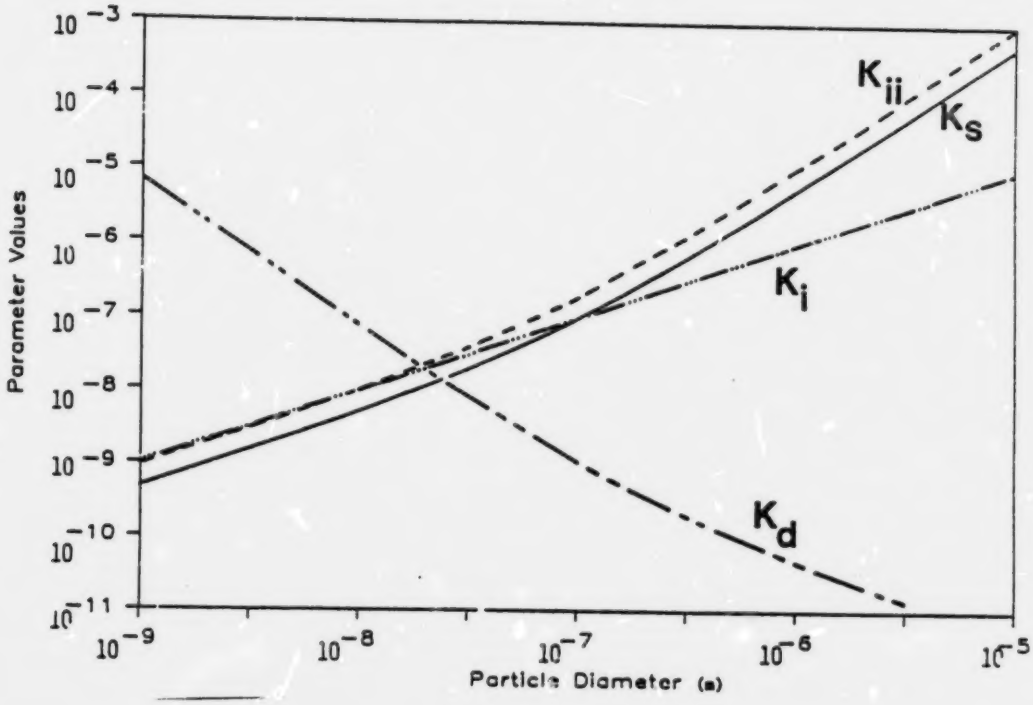


FIGURE 3-1

Variation in Collection Parameters with Particle Diameter

K_{ii}: Inertial impaction
K_g: Gravitation settling
K_i: Direct interception
K_d: Diffusion

Source: Reference 55

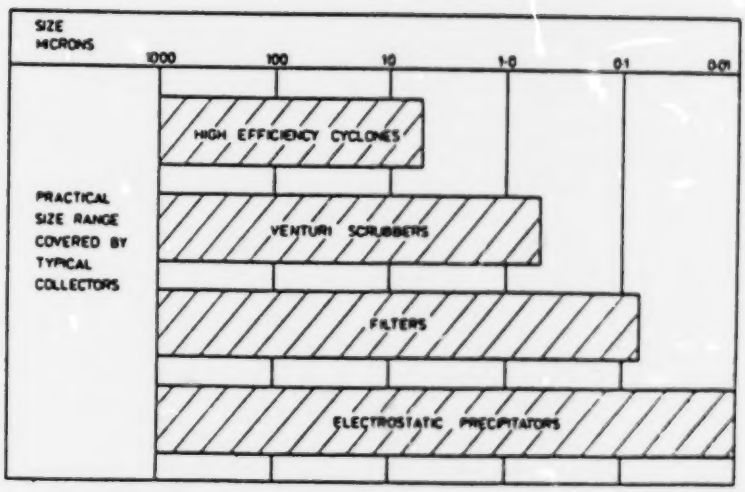


FIGURE 3-2

Range of Effectiveness of Dust Collection Devices

Source: Reference 86

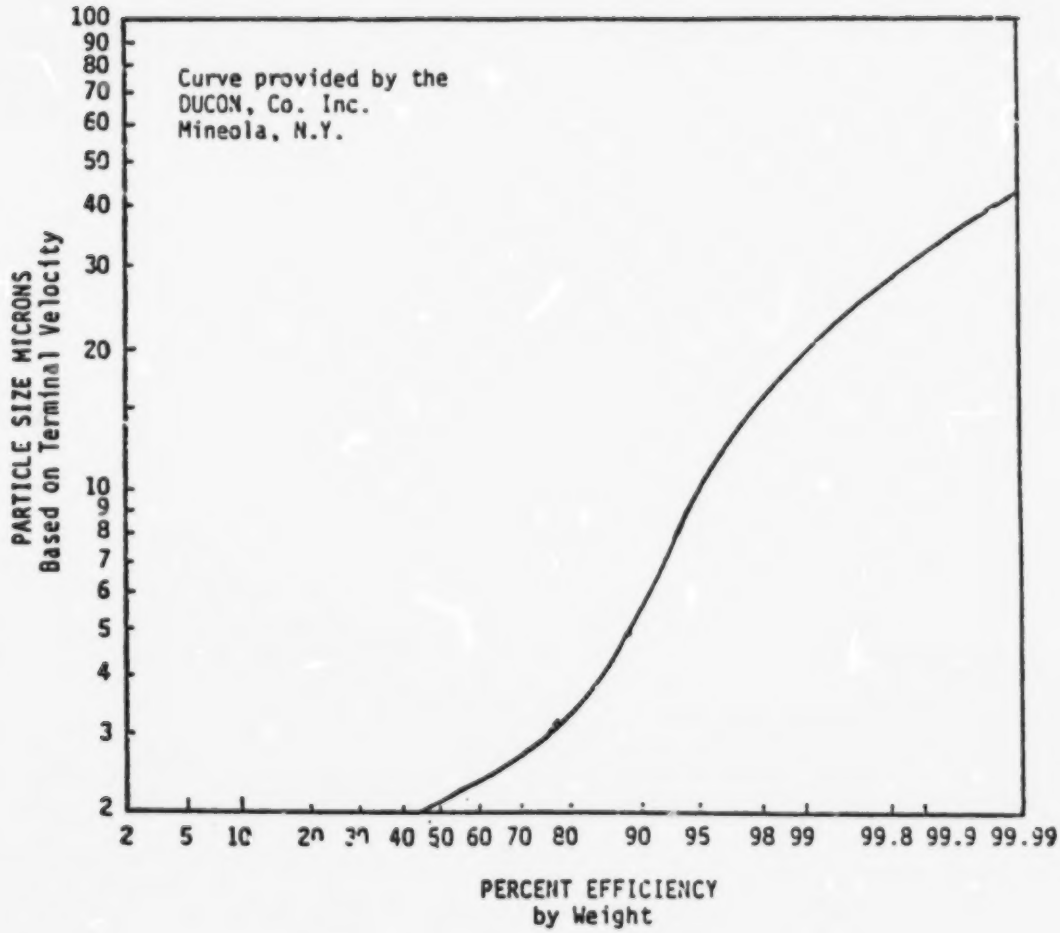


FIGURE 3-3

Cyclone Fractional Efficiency Curve

Source: Reference 81

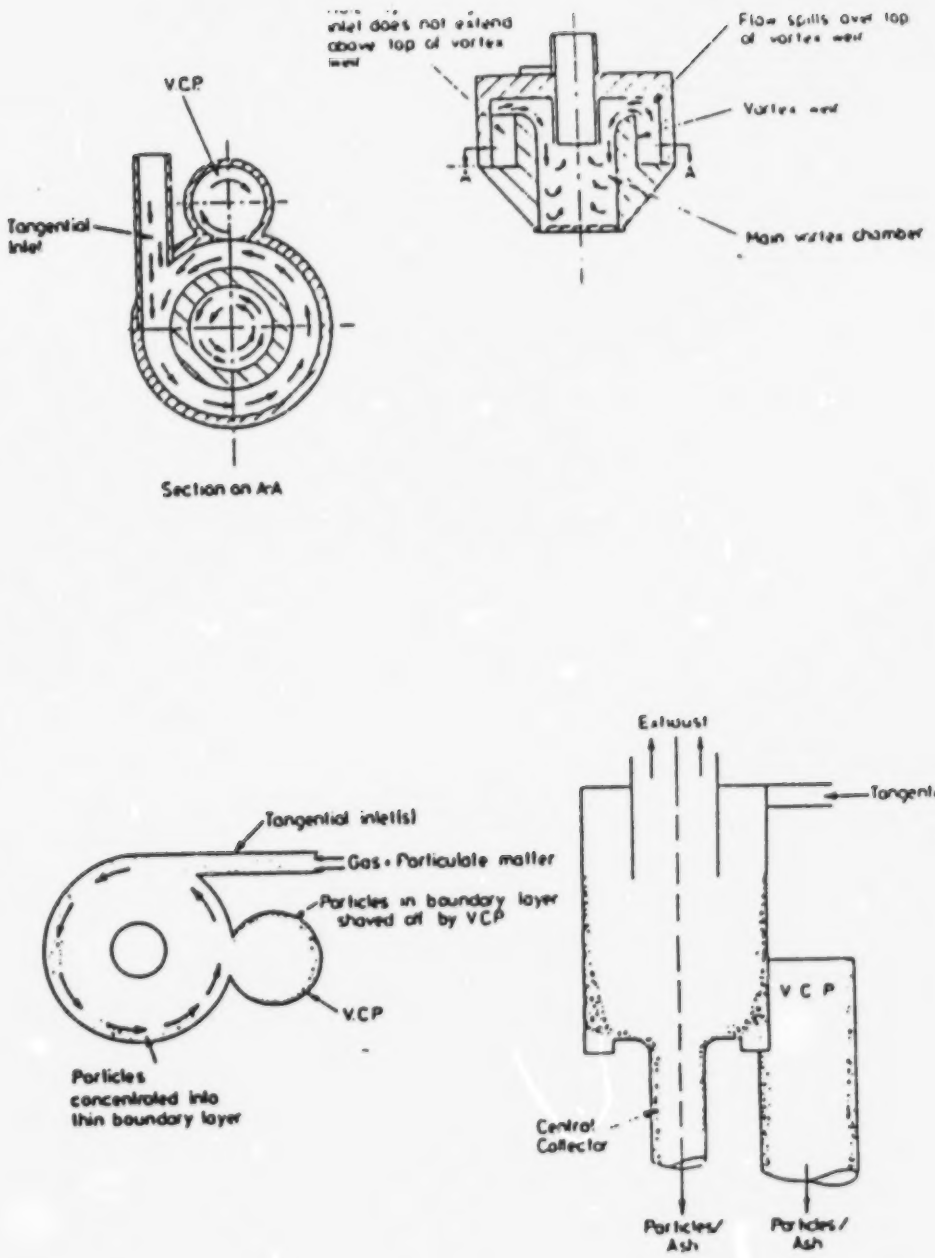


FIGURE 3-4

Cardiff Cyclone Details

Source: Reference 1

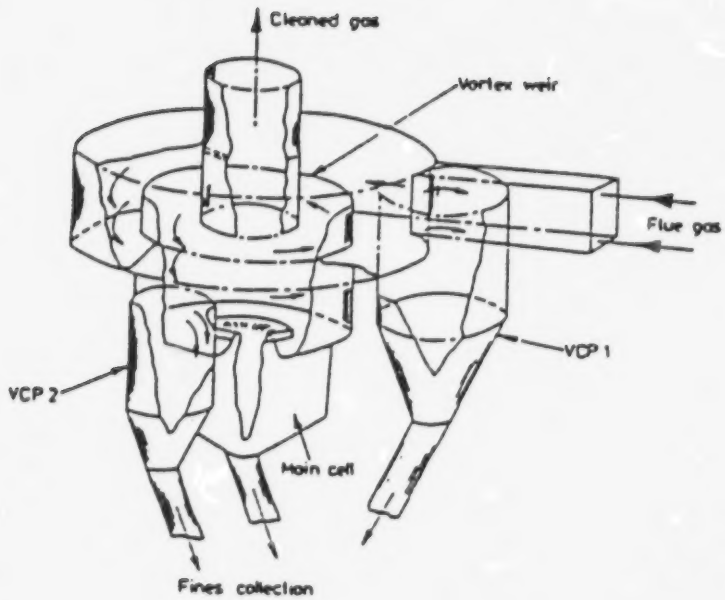


FIGURE 3-5

Cardiff Cyclone Separator

Source: Reference 1

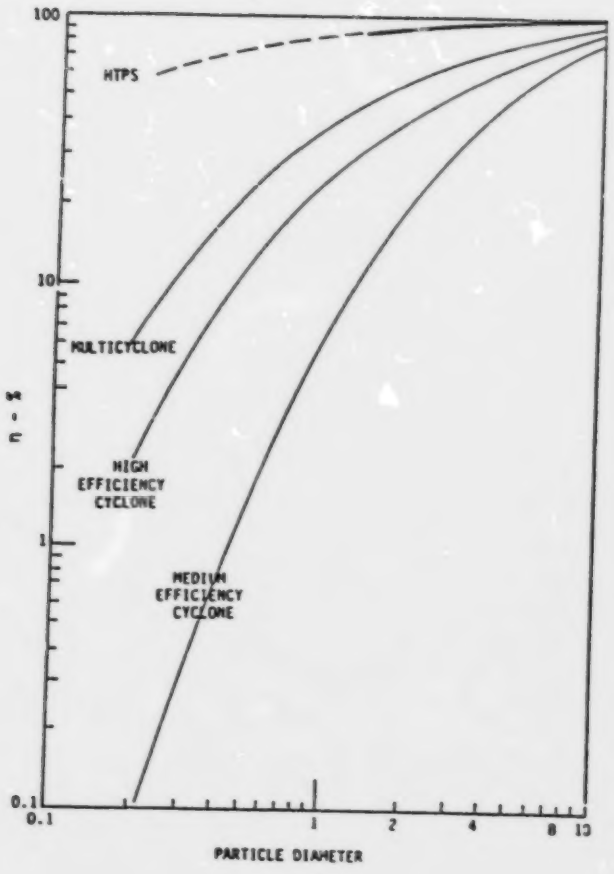


FIGURE 3-6

Comparison of Cyclone Performance

Source: Reference 74

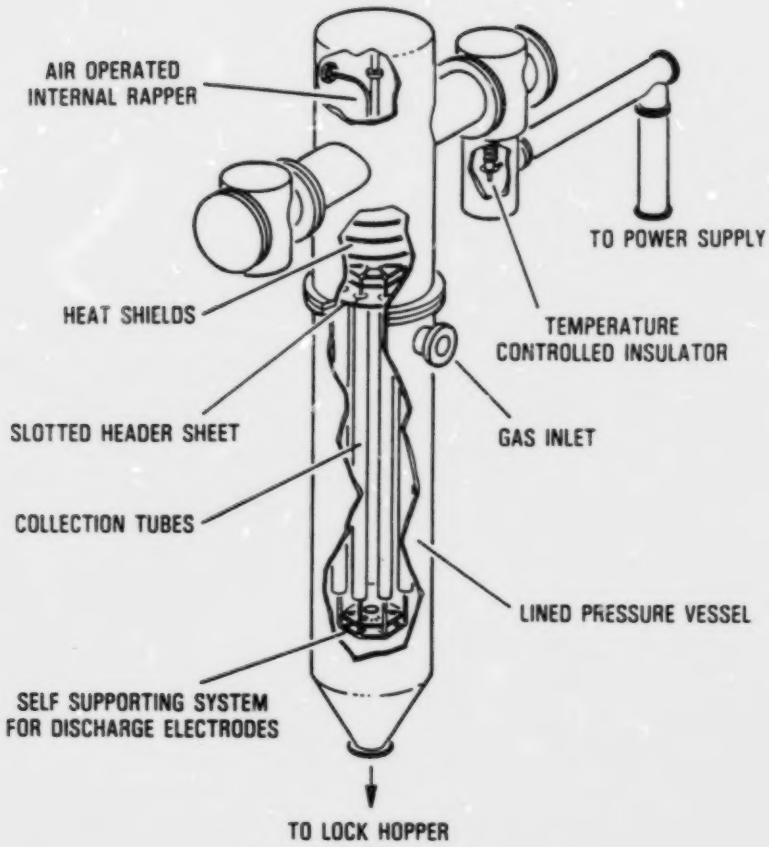


FIGURE 3-7

Research-Cottrell High-Temperature/High Pressure
Electrostatic Precipitator

Source: Reference 13

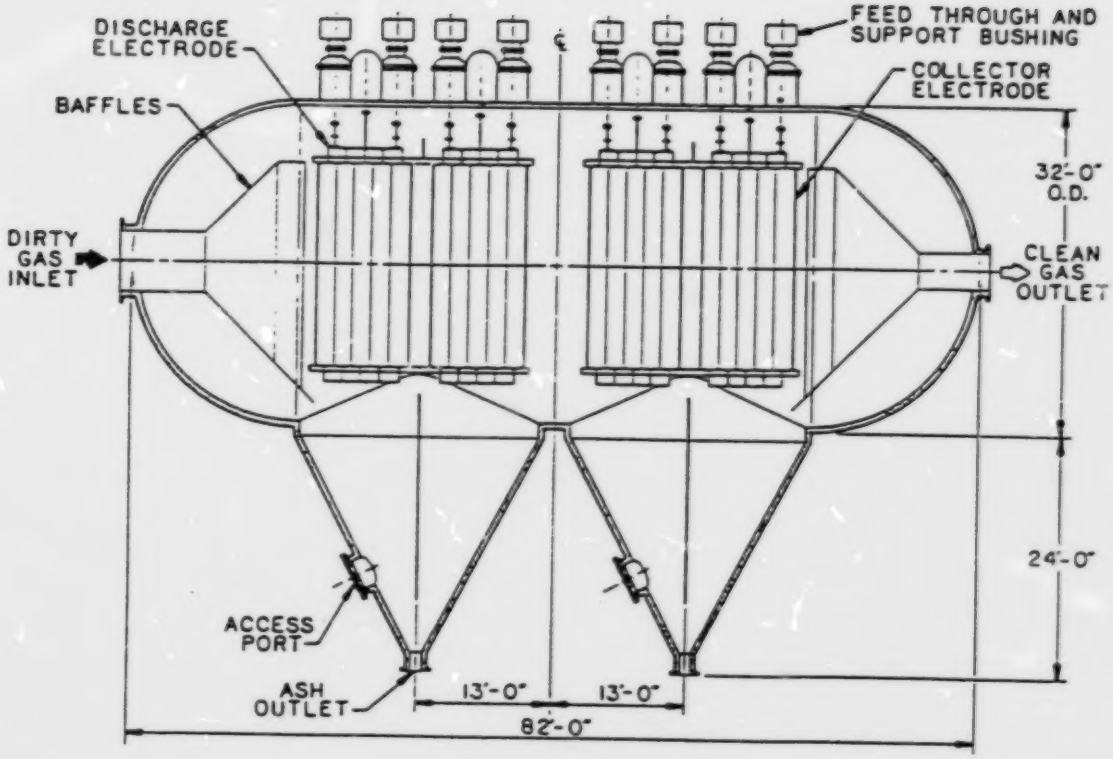


FIGURE 3-8

Research-Cottrell Commercial Concept

Source: Reference 10

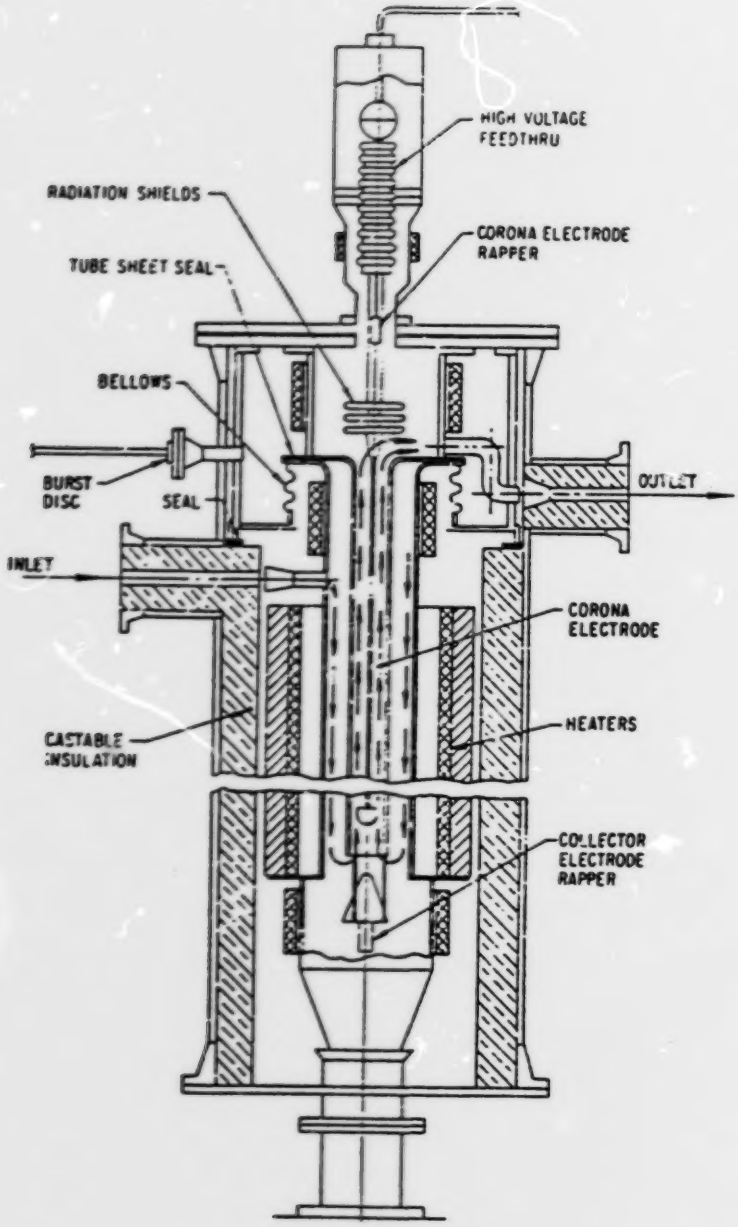


FIGURE 3-9

Denver Research Institute Electrostatic Precipitator Schematic

Source: Reference 43

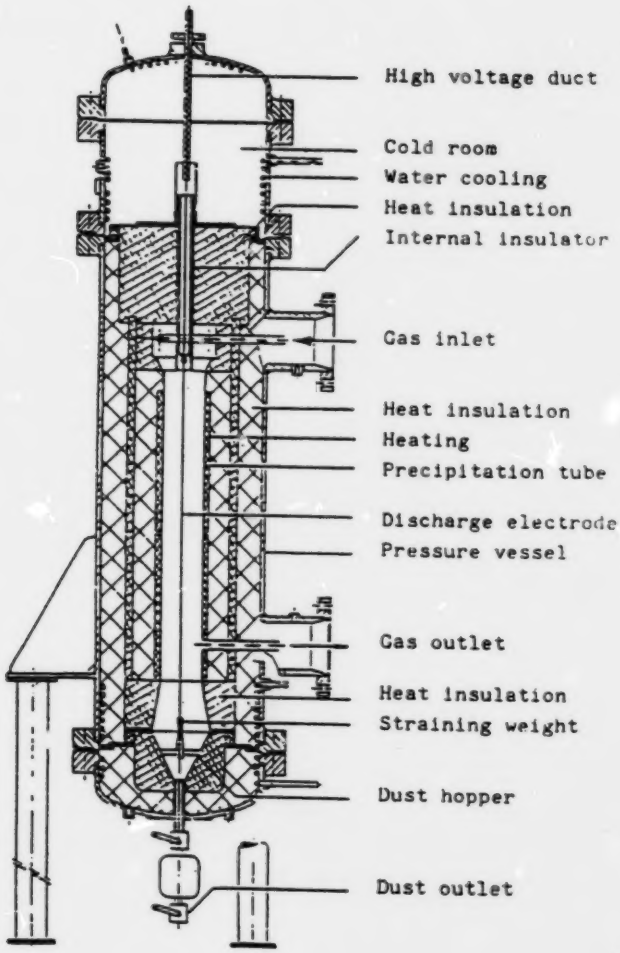


FIGURE 3-10

University of Essen High-Temperature/High-Pressure Electrostatic Precipitator

Source: Reference 83

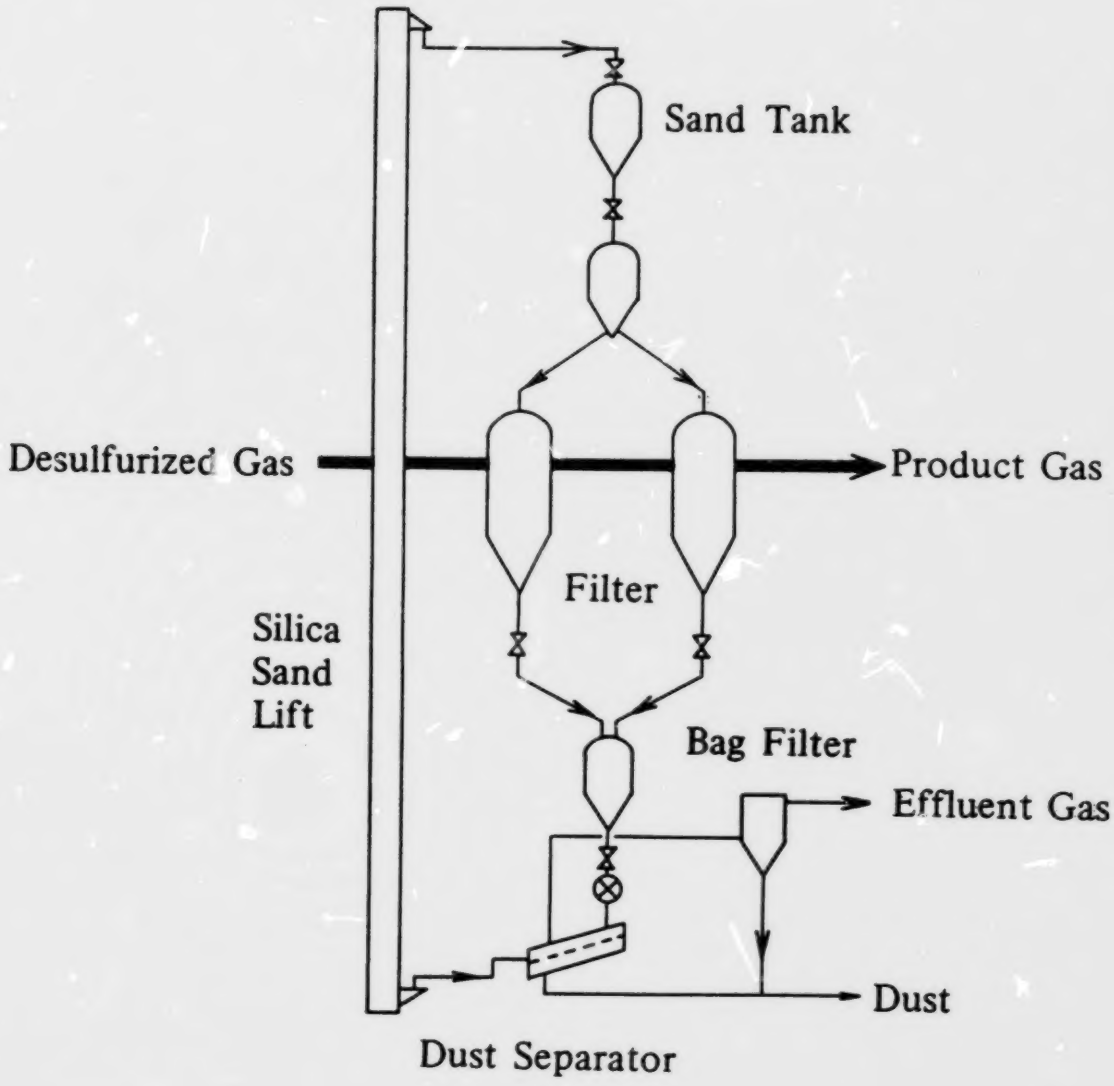


FIGURE 3-11

CMRC Moving Bed Granular Filter

Source: Reference Coal Mining Research Centre, Tokyo

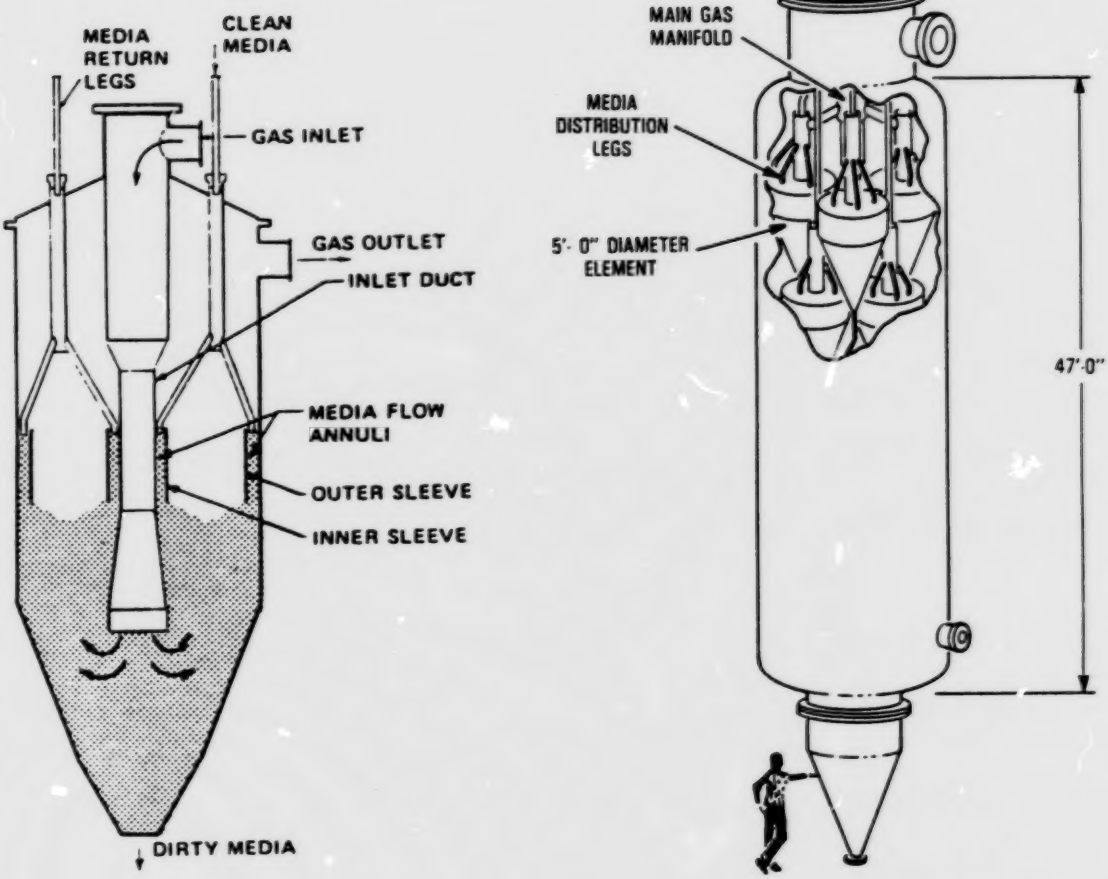


FIGURE 3-12

Screenless Granular-Bed Filter

Source: Reference 13

FIGURE 3-13

Static Granular-Bed Filter Concept

Source: Reference 13

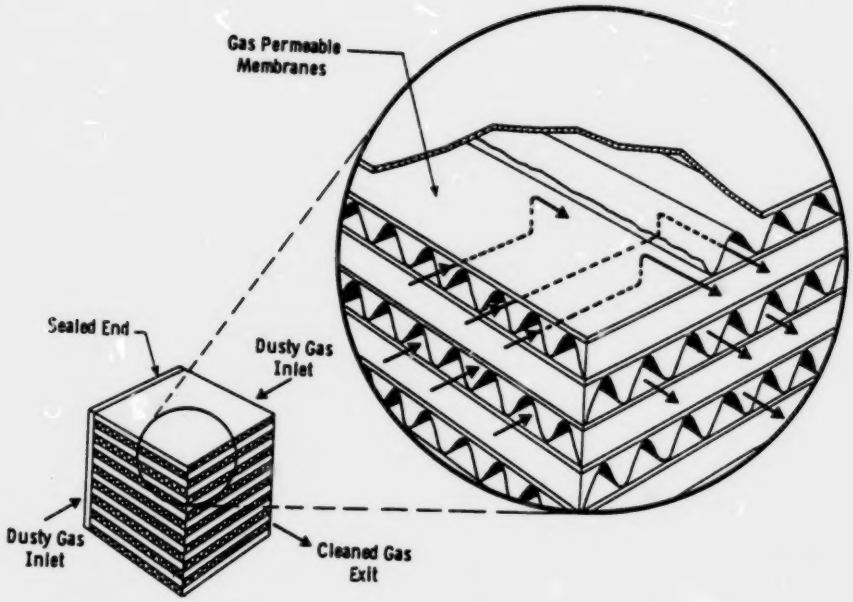


FIGURE 3-14

Westinghouse Ceramic Cross-Flow Filter Concept

Source: Reference 13

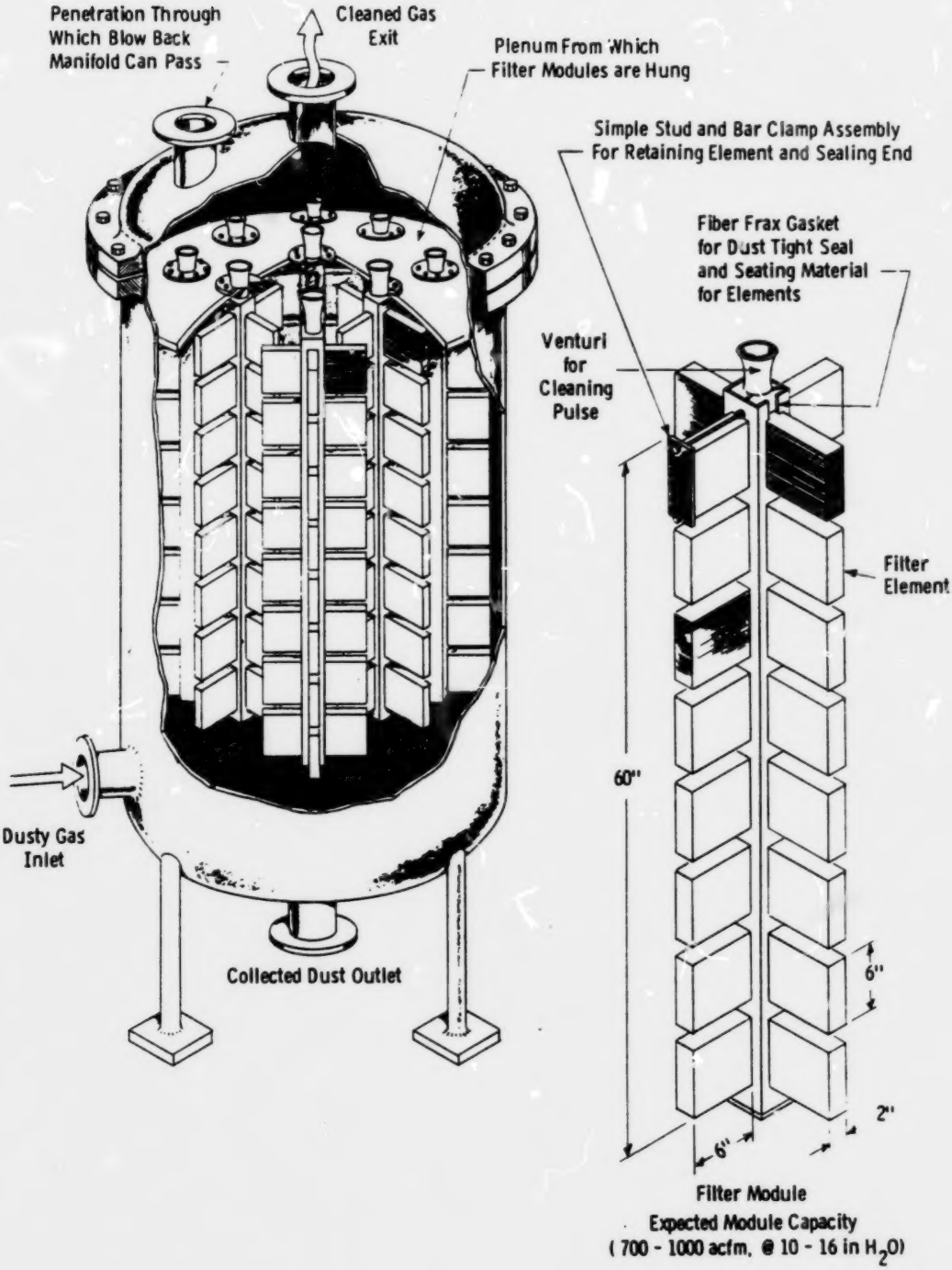

Penetration Through Which Blow Back Manifold Can Pass
Cleaned Gas Exit
Plenum From Which Filter Modules are Hung
Simple Stud and Bar Clamp Assembly For Retaining Element and Sealing End
Fiber Frax Gasket for Dust Tight Seal and Seating Material for Elements
Venturi for Cleaning Pulse
Filter Element
60"
6"
2"
6"
Dusty Gas Inlet
Collected Dust Outlet
Filter Module
Expected Module Capacity
(700 - 1000 acfm, @ 10 - 16 in H_2O)

FIGURE 3-15

Ceramic Cross-Flow Filter Module and Assembly

Source: Reference 13

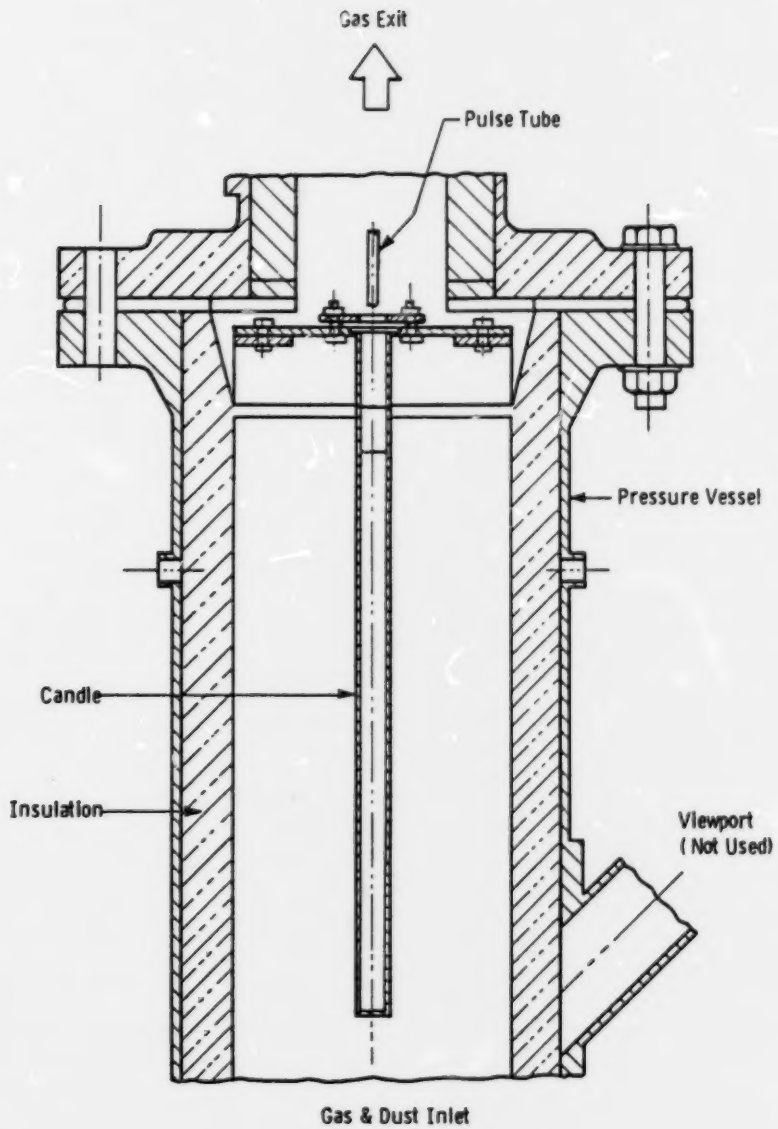


FIGURE 3-16

Ceramic Candle Filter Test Arrangement

Source: Reference 79

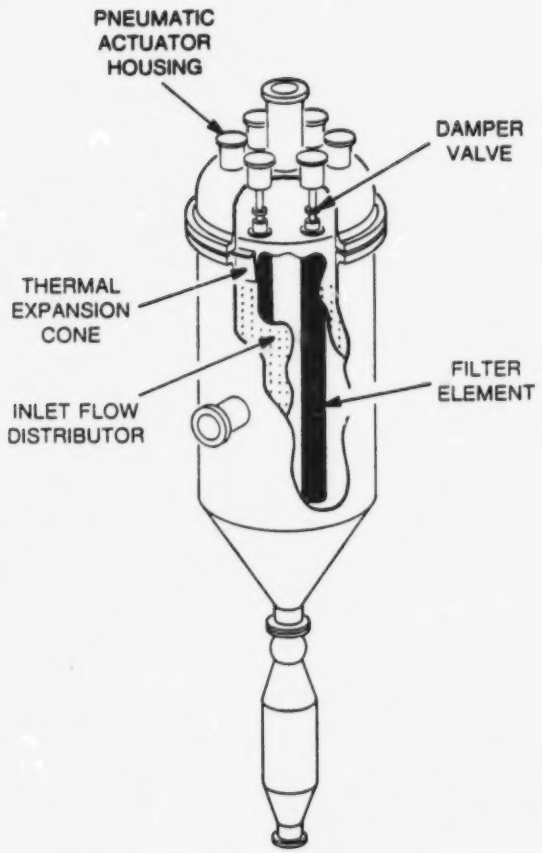


FIGURE 3-17

Acurex Ceramic Bag Filter Unit

Source: Reference 13

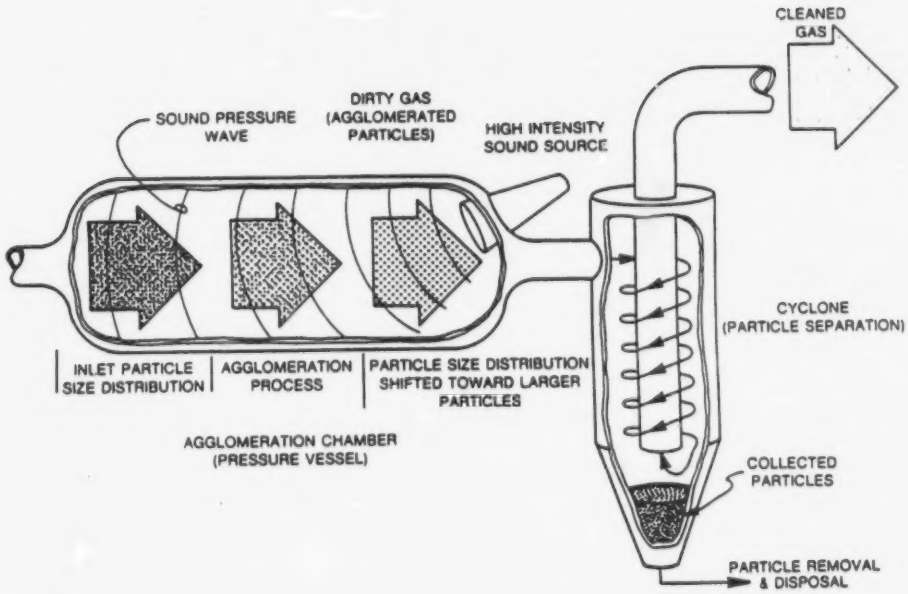


FIGURE 3-18

Acoustic Agglomeration Concept

Source: Reference 13

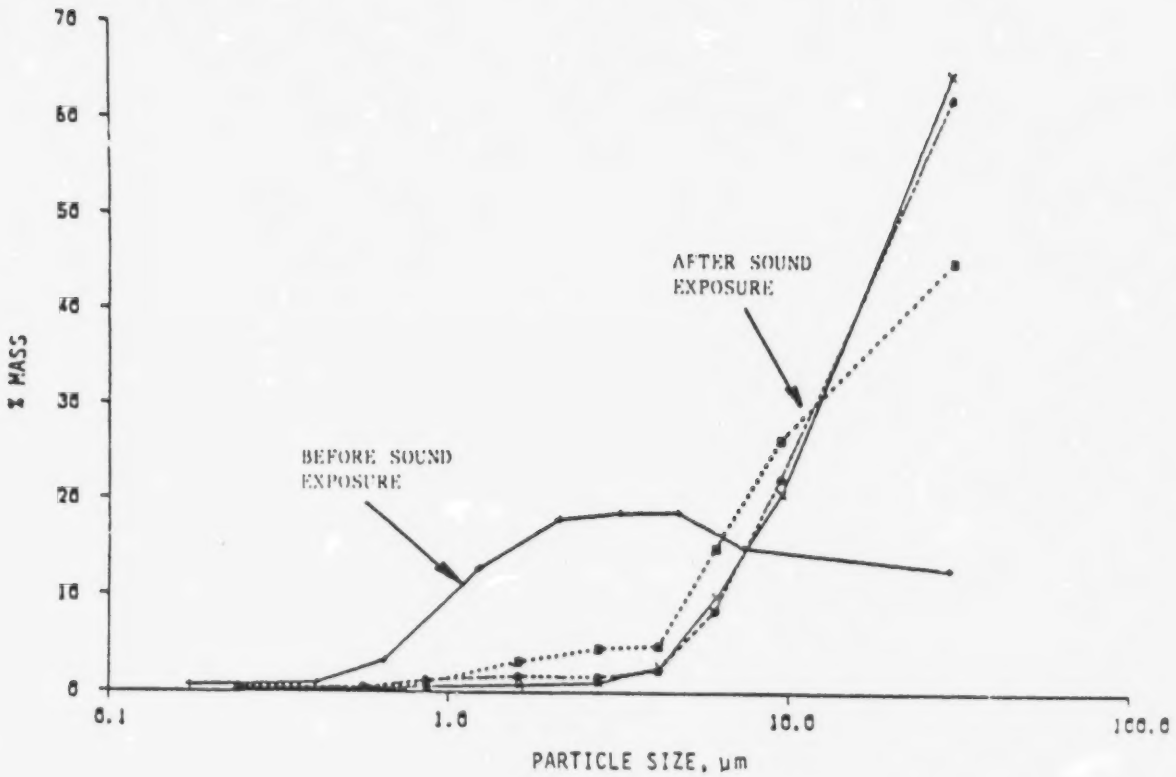
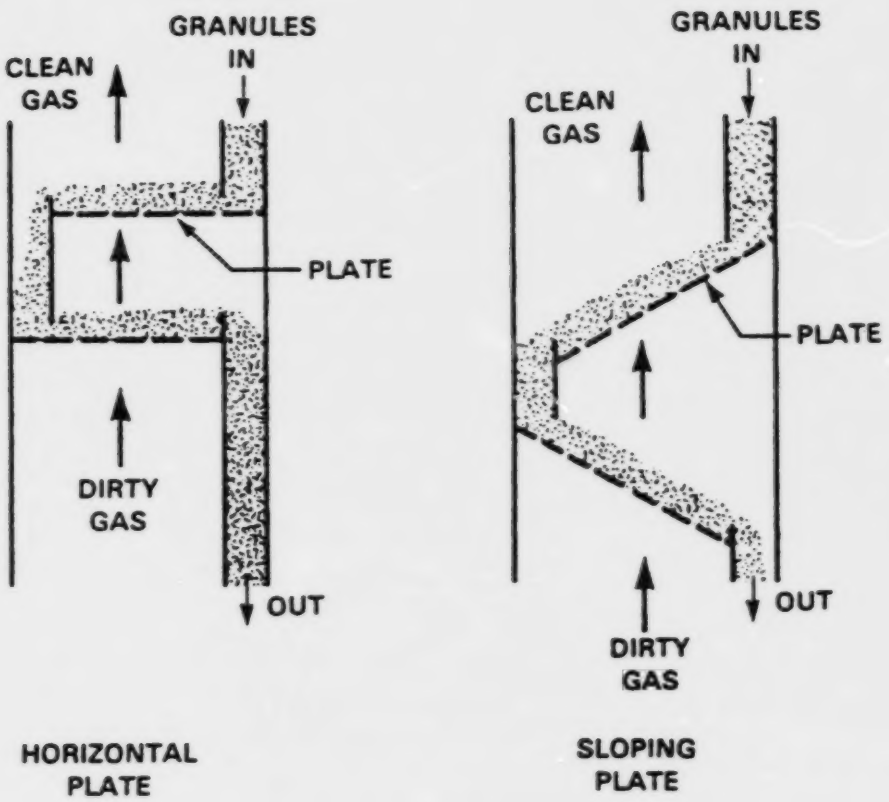


FIGURE 3-19

Agglomerator Performance

Source: Reference 36



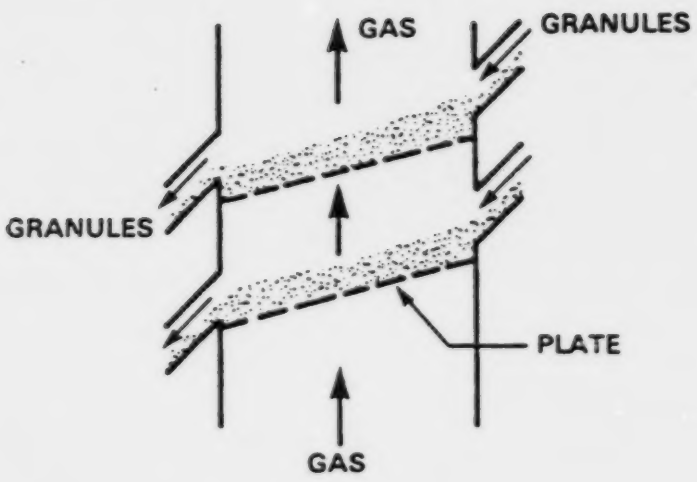


FIGURE 3-20

Dry Plate Scrubber Concept

Source: Reference 13

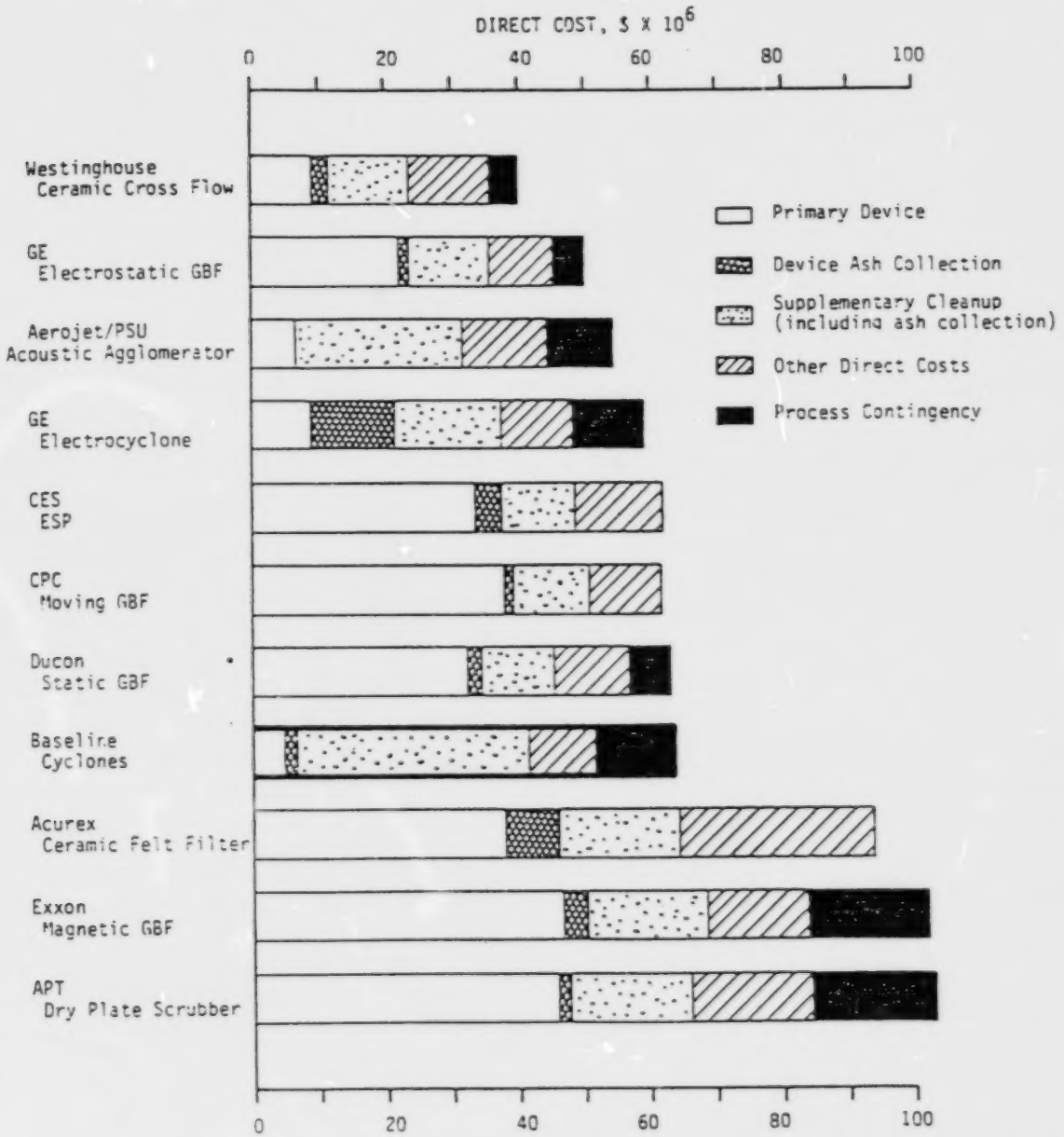


FIGURE 3-21

Comparison of Particulate Removal Device Direct Capital Costs

Source: Reference 10

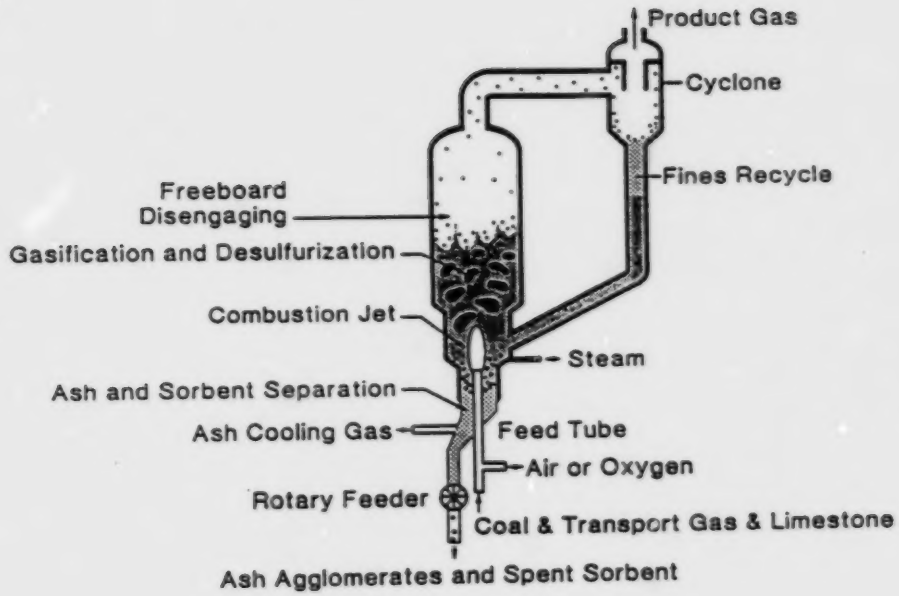


FIGURE 3-22

KRW Gasifier Schematic

Source: Reference 120

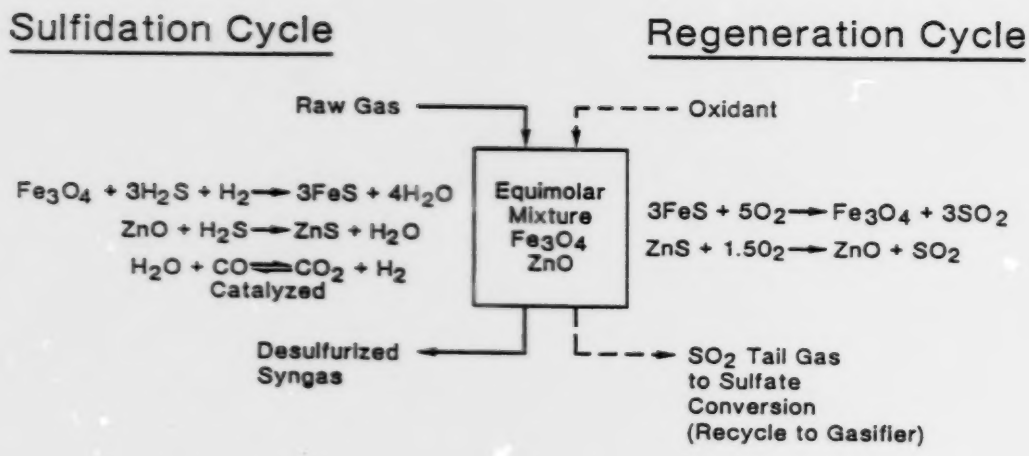

Sulfidation Cycle
Regeneration Cycle
Raw Gas
Oxidant
$Fe_3O_4 + 3H_2S + H_2 \rightarrow 3FeS + 4H_2O$
$ZnO + H_2S \rightarrow ZnS + H_2O$
$H_2O + CO \rightleftharpoons CO_2 + H_2$
Catalyzed
Equimolar Mixture Fe_3O_4 ZnO
$3FeS + 5O_2 \rightarrow Fe_3O_4 + 3SO_2$
$ZnS + 1.5O_2 \rightarrow ZnO + SO_2$
Desulfurized Syngas
SO_2 Tail Gas to Sulfate Conversion (Recycle to Gasifier)

FIGURE 3-23

Zinc Ferrite Desulphurization Reactions

Source: Reference 120

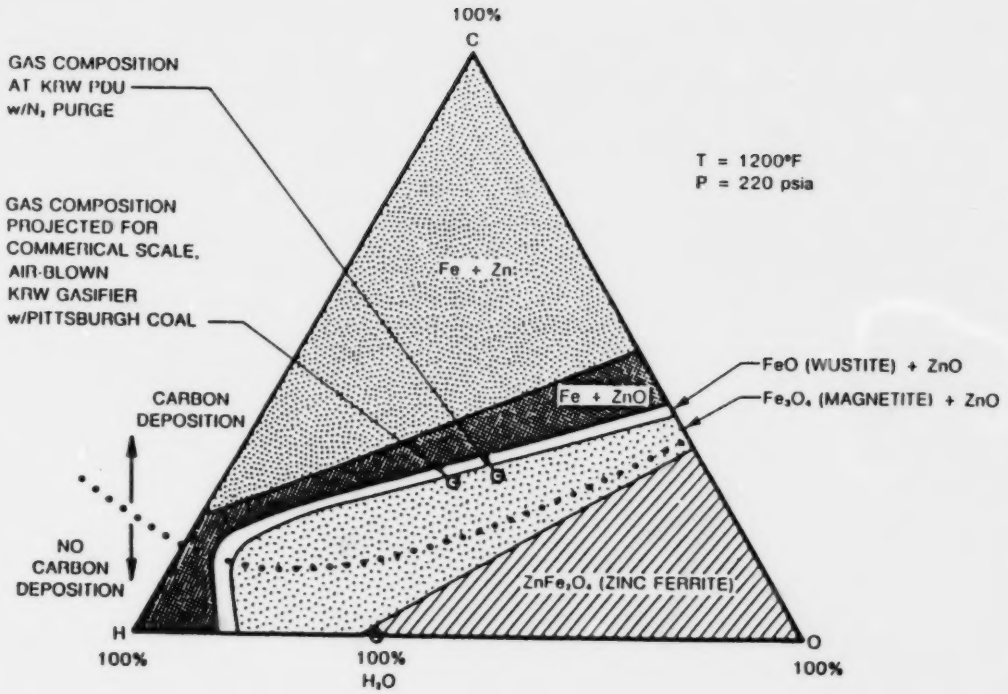


FIGURE 3-24

Zinc Ferrite Phase Diagram

Source: Reference 116

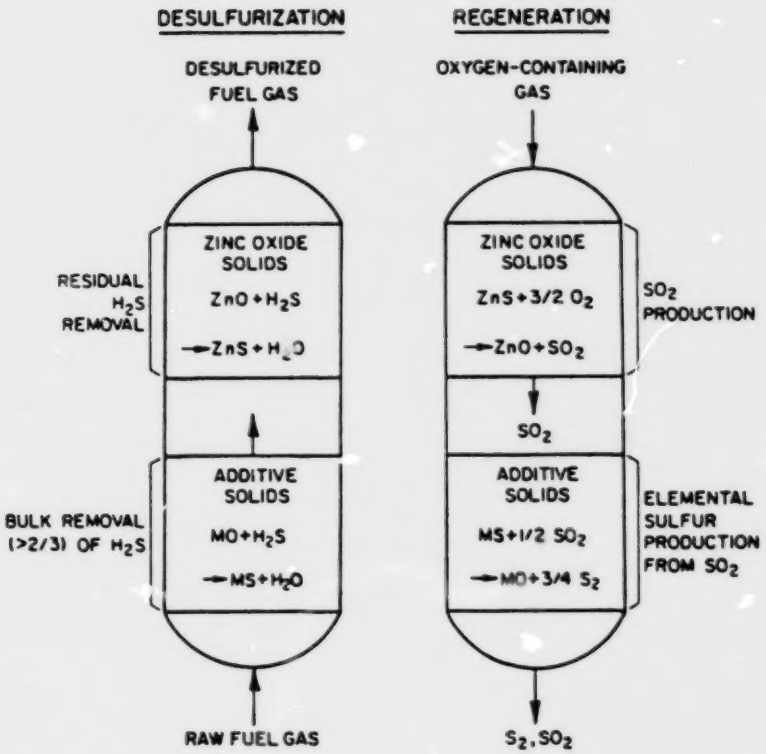


FIGURE 3-25

IGT Mixed Metal Oxide Process Concept

Source: Reference 112

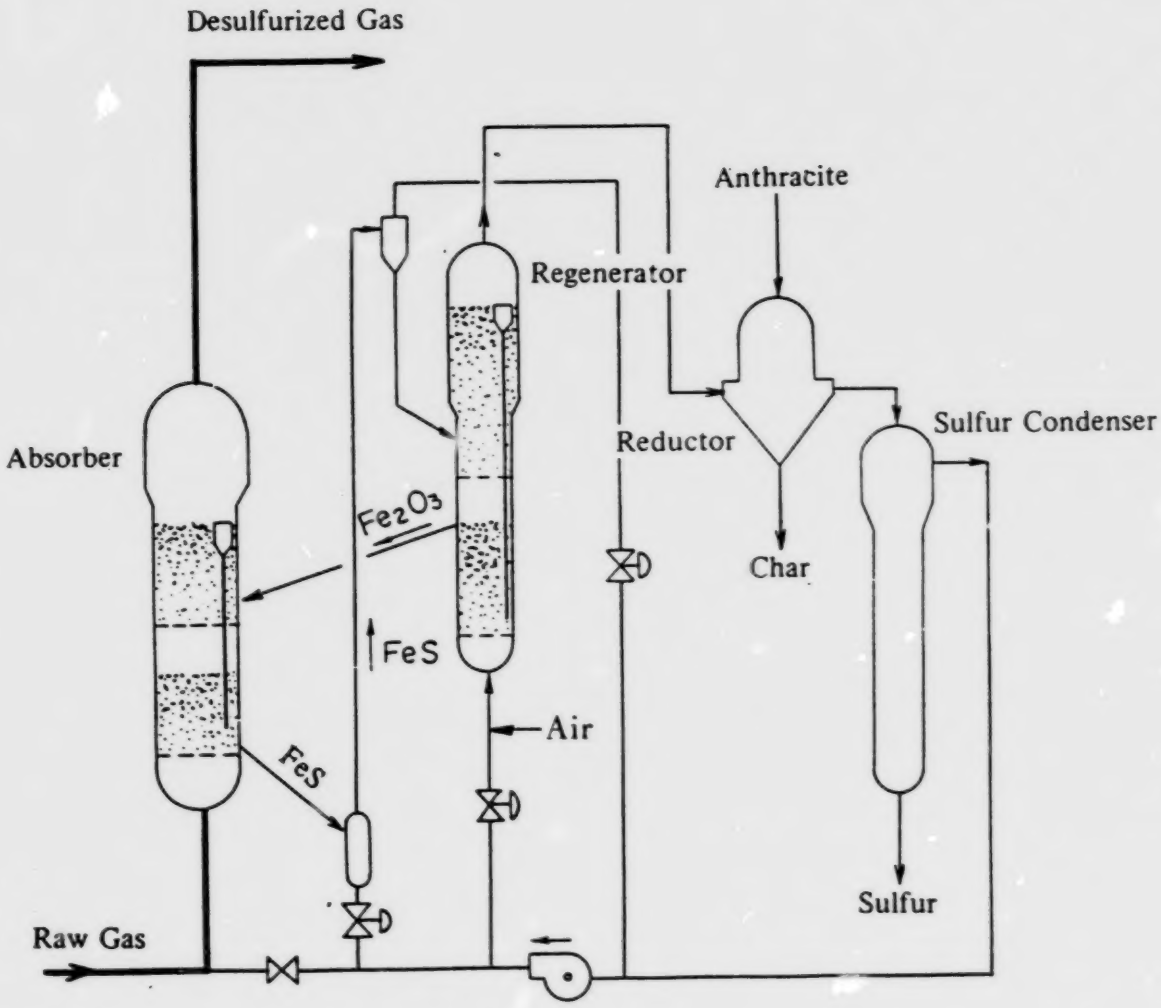


FIGURE 3-26

CMRC Iron Oxide Desulphurizer Process Schematic

Source: Coal Mining Research Centre, Tokyo

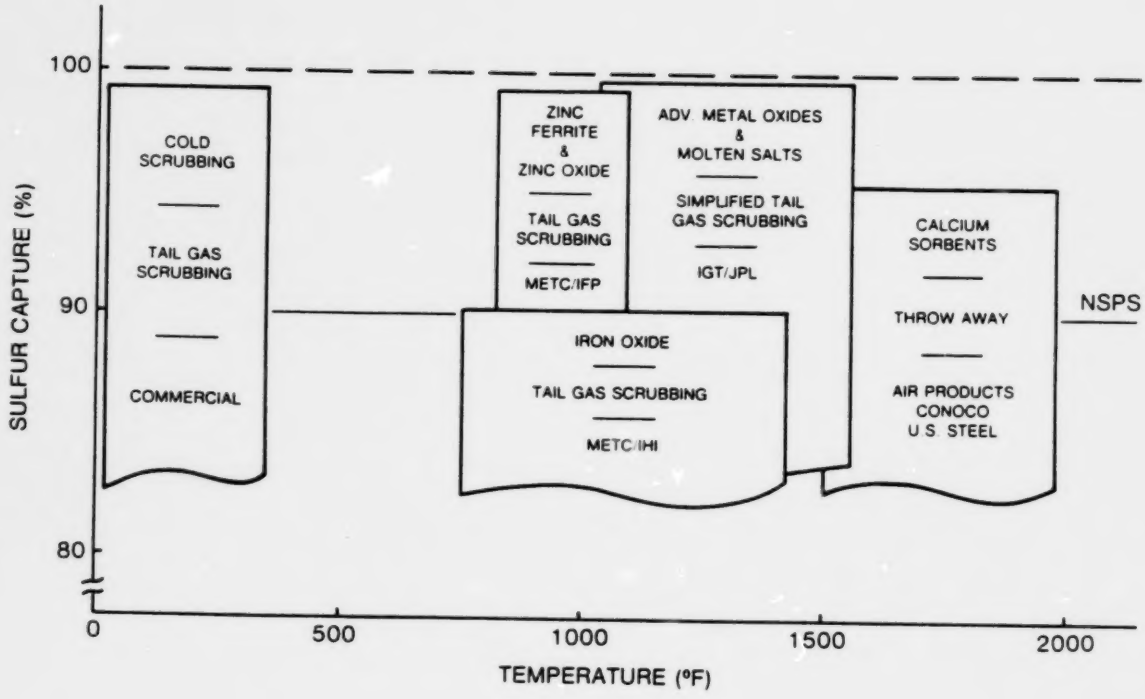


FIGURE 3-27

Comparison of Fuel Gas Desulphurization Processes

Source: Reference 91

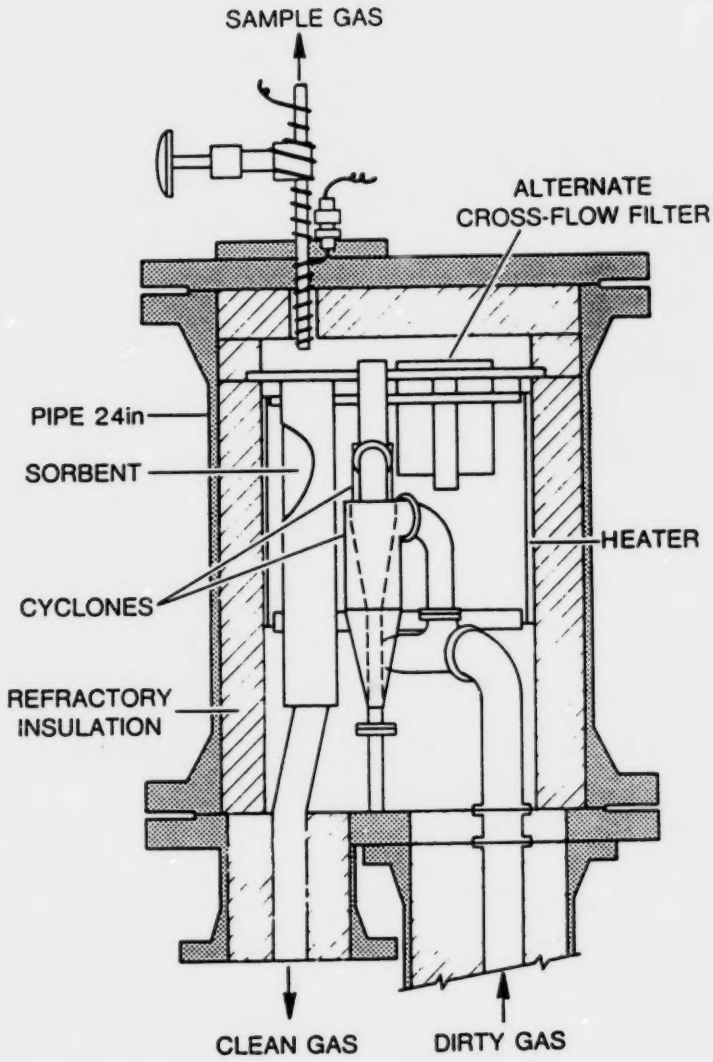


FIGURE 3-28

Argonne National Laboratory Alkali Sorber Schematic

Source: Reference 4

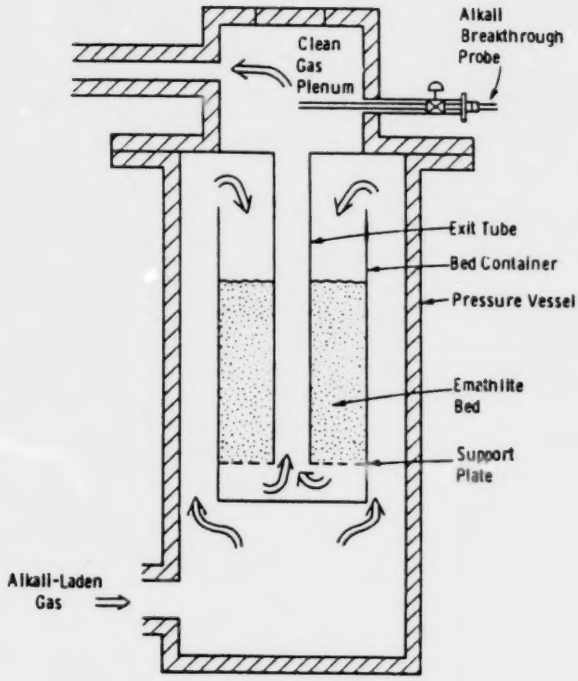


FIGURE 3-29

Westinghouse Emathlite Alkali Absorber Schematic

Source: Reference 95

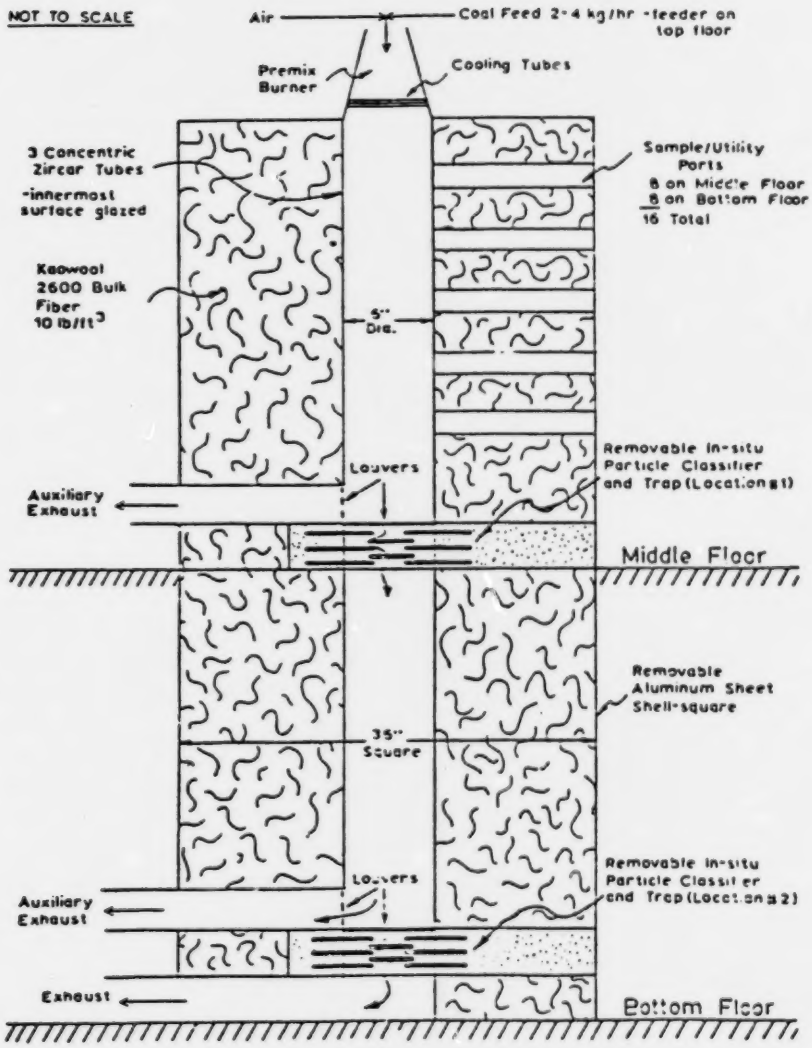


FIGURE 3-30

University of Arizona Downward Firing Plane Flame Reactor

Source: Reference 45

PART 4

REVIEW OF COMMERCIAL GASIFIER CLEANUP SYSTEMS

PART 4 - REVIEW OF COMMERCIAL GASIFIER CLEANUP SYSTEMS

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4.2	TEXACO	4-1
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4.4	DOW	4-3
4.5	BGC/LURGI	4-3
4.6	KRW	4-4

TABLES

Table

4-1 Commercial Gasifier Cleanup Systems

4.1 INTRODUCTION

A number of gasifiers are under development in the U.S. and elsewhere for use in IGCC power generation, synthesis gas, substitute natural gas and fuel gas applications. In each of these applications there is a recent North American example: the 100 MW Cool Water demonstration of IGCC at Daggett, California; the Tennessee Eastman acetic anhydride manufacturing facility at Kingsport, Tennessee; the Great Plains SNG project at Buelah, North Dakota; and the Shell gasification demonstration of fuel gas production at Deer Park, Houston, Texas.

In each of these projects low temperature gas cleanup is used. This part of the report briefly reviews the cleanup technologies used by the major commercial or near commercial gasification technologies. Attempts have been made to find out what plans the major developers have for introducing hot gas cleanup in the future, but little information has resulted due to the developers' reluctance to discuss plans for proprietary processes.

A summary of the gasification processes, projects in which they are used, and the cleanup systems is given in Table 4-1.

4.2 TEXACO

The entrained flow Texaco gasification process has been used in a large number of applications, mainly for the production of synthesis gas such as at the Tennessee Valley Authority ammonia from coal demonstration plant, Muscle Shoals, Tennessee (125); the Tennessee Eastman acetic anhydride plant at Kingsport, Tennessee (128); and the Ube Chemicals ammonia plant, Ube, Japan (127). It is also used at the Cool Water IGCC demonstration project in Daggett, California (126).

All of these projects utilize conventional, low temperature gas cleanup technologies. Particulates are first scrubbed from the hot gas by water scrubber. Sulphur in the form of H_2S is removed by either a Selexol or a Rectisol process plant. In the case of the TVA Ammonia from coal project, the COS is first hydrolyzed to H_2S as the COS is not removed by the Stretford process. High sulphur capture efficiencies are achieved.

No information was received from Texaco as a result of an enquiry in regard to future plans for the use of hot gas cleanup.

4.3 SHELL

The Shell entrained flow gasification process has been under development by Shell in the Netherlands since the early 1970s. In 1978, a 165 t/d plant started up at the Shell refinery at Hamburg, West Germany. A pilot plant is currently nearing completion at the Shell Deer Park facility near Houston, Texas.

This plant is the first North American demonstration of the Shell Process and is designed to produce a fuel gas for use in the refinery. Very little information has been published on this project and it is not known which cleanup processes are being used to remove sulphur. Shell declined to provide any information on their plans for future use of hot gas cleanup on the grounds that such information was proprietary.

A study of Shell based IGCC applications was carried out for EPRI by Fluor (129). For the purposes of the study Fluor assumed that the Selexol process would be used, but there is no information available to indicate whether this process would be used on an actual plant.

4.4 DOW

Dow has been developing an entrained flow gasification process since the early 1970s. This process uses a two stage injection of the coal slurry feed and has potentially a higher conversion efficiency than other processes.

The construction of a demonstration project at the Dow Plaquemine plant is nearing completion with startup expected shortly. This will convert 2200 t/d of lignite to medium heating value gas for use in gas turbines for power generation (130).

According to Dow, a wide variety of commercially available removal processes can be used with this gasification process, depending on the end use. At the present time, Dow has no plans to use hot gas cleanup but are aware of the work of DOE and others and will adopt the concept once it has been proven commercially.

4.5 BGC/LURGI

This process, basically a slagging version of the Lurgi gasifier, has been under development by British Gas Corporation since the early 1970s. By injecting oxygen into the gasifier zone, the temperature is raised sufficiently high to slag the ash. A 550 t/d pilot plant equipped with a 27 MW gas turbine is in operation Westfield, Scotland.

The process uses low temperature gas cleanup. This fixed bed gasifier produces a range of tars and oils which are condensed from the gas stream in the coolers. Particulates are also removed with the condensing liquids. Sulphur is removed using a Lurgi hot potassium carbonate process. A study evaluating the use of BGC/Lurgi gasifier in

IGCC applications was carried out for EPRI by the Ralph M. Parsons Company (131).

The use of hot gas cleanup with a fixed bed process may not be practical due to the presence of the tars and oils which would rapidly contaminate the process equipment. For a fixed bed process, the lower temperature of the produced gas provides less of an incentive for the use of hot gas cleanup and it is unlikely that it would be applied to this type of process.

4.6 KRW

The KRW gasifier is one of the few processes which promise to make use of hot gas cleanup in the near future. The use of in-bed sulphur capture by limestone or dolomite addition is described in Part 332 of this report. Captures of up to 95% have been obtained in recent tests (120).

In addition to the use of the in-bed sulphur capture, KRW is also planning to make use of the zinc ferrite external hot gas cleanup process to reduce sulphur levels to the 10 ppmw range. This process is described in Part 333 of this report.

KRW is currently involved in two commercial scale projects, the Appalachian IGCC project in southern Pennsylvania, and the Fularji gasification project in China. The Appalachian project, which will produce about 60 MW of power, will use both in-bed and external cleanup processes as a demonstration, although the in-bed capture in more than sufficient to meet NSPS requirements. Particulate material will be removed by a combination of cyclones and hot gas filters. The exact filter type has not yet been fixed, pending the outcome of tests to be carried out in 1987.

The Fularji project will produce a medium heating value fuel using oxygen enriched air as an oxidant. No sulphur removal is required as the fuel gas produced is being mixed with existing coal derived gas which contains sulphur.

TABLE 4-1

Commercial Gasifier Cleanup Systems

Project	Coal Feed	Product	Cleanup System		Comments
			Sulphur Removal	Particulate	
Texaco:					
TVA Ammonia	Illinois #6 & others	Ammonia	Selexol/Stretford	Wet scrubber	COS hydrolyzed to H_2S
Cool Water	Utah 0.4% suplhur	IGCC	Selexol/Claus	Wet scrubber	97% sulphur removal
UBE Chemicals	Australian	Ammonia	Rectisol/Claus	Wet scrubber	
Tennessee Eastman	Virginia & Kentucky	Acetic Anhydride	Rectisol/Claus/SCOT	Wet scrubber	99.7% sulphur removal
KRW:					
Appalachian Project	Eastern bituminous	IGCC	In-bed/zinc ferrite	Cyclone/hot filter	95%+ sulphur removal
Fularji, China	Lignite	Fuel gas	None	Cyclone/hot filter	No sulphur removal required
Shell:					
Studies	Illinois #6	IGCC	Selexol/Claus	Cyclone/wet scrubber	90% sulphur removal
Houston Demonstration	Lignite	Fuel gas	N/A	N/A	No details available
Dow: Plaquemine	Lignite	IGCC	GAS/SPEC ST-1/Selectox	Cyclone/wet scrubber	Sulphur removal N/A
BGC/Lurgi:					
Studies	Illinois #6	IGCC	Hot potassium carbonate/Claus	Removed with oil/tar	90% sulphur removal

PART 5

HOT GAS CLEANUP RESEARCH IN CANADA

PART 5 - HOT GAS CLEANUP RESEARCH IN CANADA

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5.3	UNIVERSITY	5-2
5.4	INDUSTRY	5-4

Figures

5-1 Schematic Diagram of UBC Gasifier

5-2 Vortex Pocket Cyclone Tested at UBC

5-3 Granular Bed Filter Tested by UBC

5.1 INTRODUCTION

A brief review of Canadian hot gas cleanup research work was carried out. This included Federal and Provincial government levels, university and private industry. This part of the report reviews the results of this survey.

Although there has been considerable work carried out in the field of gasification in the last 10 years, very little has been carried out in hot gas cleanup specifically.

5.2 GOVERNMENT AGENCIES

The Gasification and Pyrolysis section of the Combustion and Carbonization Laboratory at the Energy Research Laboratories of CANMET, Ottawa has carried out research in this area. The work has been focused on the development of solid adsorbents to remove acidic compounds at high temperatures (121).

As considerable work has been carried out in the U.S. in this area using relatively expensive materials such as zinc ferrite and metal oxides which require regeneration to be economical, the CANMET work concentrated on the use of low cost materials. The concept is to use these as "throwaway" sorbents which can be safely disposed of after use. Materials considered for this application include naturally occurring clays, and by-products resulting from the production of metals such as aluminum, nickel and steel.

Tests have been carried out using materials such as limestone, iron oxide, red mud, and manganese nodules. Among the results obtained, it was shown that the amount of sulphur capture depends on the type of

clay component with which the iron is associated. The addition of calcium to iron containing compounds was also shown to be beneficial.

In Alberta, considerable gasification research has been carried out by government agencies such as the Alberta Office of Coal Research and Technology and the Alberta Research Council, but to date none of this has been concerned with hot gas cleanup.

5.3 UNIVERSITY

The University of British Columbia (UBC) has carried out a study in hot gas cleanup under contract by CANMET using its 30 to 50 kg/hr spouted/fluidized bed gasifier (133). This gasifier has been used to gasify a wide range of Alberta and B.C. coals as well as coke from oil sands upgrading.

This study was carried out to test three particulate collection devices on the UBC pilot scale atmospheric pressure gasifier. The devices tested were standard cyclones, a vortex pocket cyclone and a granular bed. Gasifier feedstocks used included coal and petroleum coke. A schematic diagram of the gasifier is shown in Figure 5-1.

The two standard cyclones were used in series with an inlet velocity of from 14.6 to 19 m/s at temperatures ranging from 740 to 910°C at the primary cylcone inlet. Measured inlet dust loadings of up to 200,000 ppmw were obtained. The average primary cyclone efficiency was about 98.7%.

The vortex pocket cyclone used in the tests had a configuration as shown in Figure 5-2. The design was based on the Cardiff cyclone described in Part 322 (1). The inlet cross sectional area is considerably reduced over conventional cyclones with a corresponding increase in inlet

velocity. The tests were carried out to determine if enhanced collection efficiences in the collection of small particles could be achieved under gasification conditions.

A comparison of the vortex pocket cyclone and a standard cyclone as secondary collectors did not show very significant differences. Dust loadings at exit from the cyclones averaged 370 ppmw for the standard cyclone and 250 ppmw for the vortex pocket cyclone. However, practical difficulties in the measurement of the loadings make these results somewhat doubtful.

Using the vortex pocket cyclone as a primary collector gave an average efficiency of 99.3%. Outlet dust loadings averaged around 400 ppmw which was about one sixth the level of the standard cyclone. Inlet dust loadings were, however, about half those of standard cyclone tests. It is interesting to note that the ash content of the material collected in the vortex pocket collection point was about 34% compared with 67% in the main leg of the cyclone. This supports claims by the developers of this design that it can be used to separate the ash from the char.

The granular bed filter used was a counterflow device as shown in Figure 5-3. This was used as a secondary device only. The bed was filled with gravel having a mean size of 2.2 mm. Inlet dust loadings to the bed were low due the the efficiency of the vortex pocket cyclone and averaged 350 to 650 ppmw. The average collection efficiency was calculated to be about 37% and is a strong function of particle diameter. The particles collected were found to be composed largely of ash with only 15% carbon content.

The results of this program were found to be in general agreement with available results in published literature.

5.4 INDUSTRY

A number of studies have been carried out by industry into applications of gasification such as the production of chemicals, synthetic fuels and combined cycle power generation. However, none has been directed towards hot gas cleanup.

Recently, with utility interest in IGCC growing, the need for hot gas cleanup has been seen as more of a priority and the present study is a reflection of that concern.

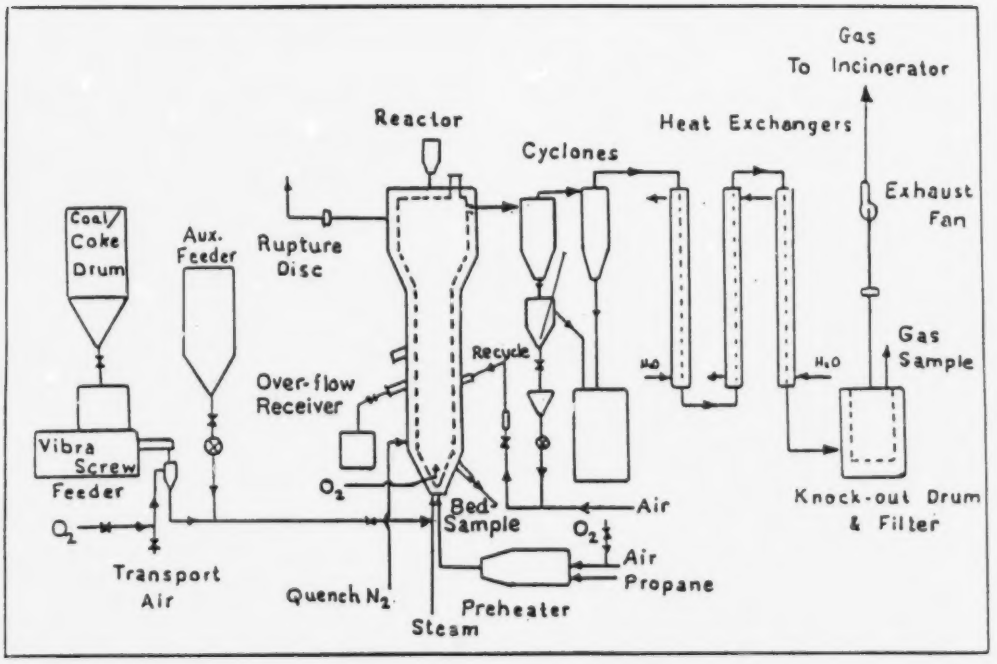

FIGURE 5-1

Schematic Diagram of U.B.C. Gasifier

Source: Reference 133

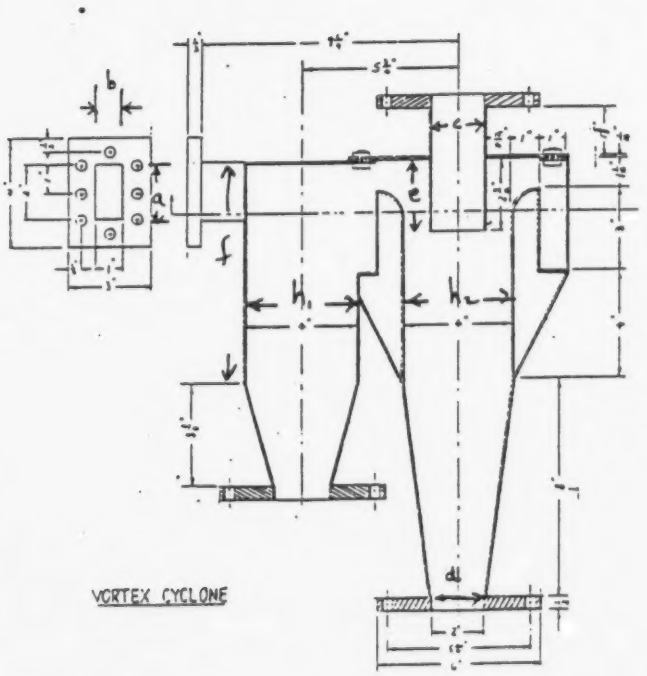

FIGURE 5-2

Vortex Pocket Cyclone Tested by U.B.C.
Source: Reference 133

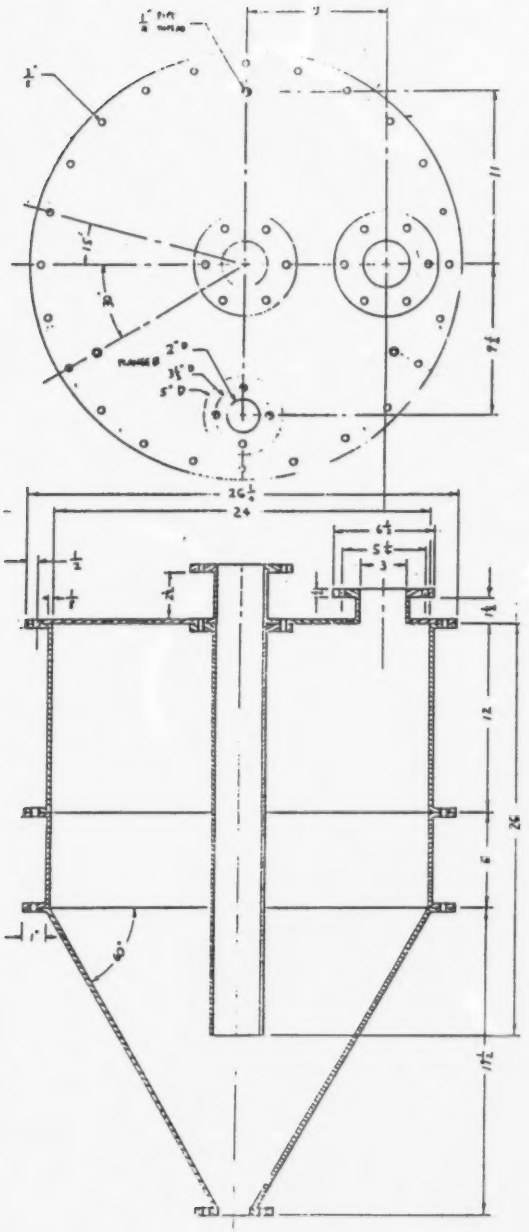

FIGURE 5-3

Granular Bed Filter Tested by U.B.C.

Source: Reference 133

PART 6

CONCLUSIONS AND RECOMMENDATIONS

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6.1 CONCLUSIONS

This review of hot gas cleanup technologies has shown that there is considerable activity in this field with the U.S. DOE as the main proponent. In general, it is concluded that hot gas cleanup technology is some way from commercial status.

Particulate Cleanup

Particulate cleanup systems are well advanced, having benefited from several years of work in connection with PFBC before gasification requirements became clear.

The most promising developments for particulate cleanup are ceramic cross flow filters and ceramic bag filters. These devices have shown good collection efficiency and promise to be easily cleaned. Although some materials and fabrication problems are still to be solved and prolonged tests in realistic atmospheres are still to be carried out, there is reasonable cause for optimism on the prospects of successful application.

Electrostatic precipitators, while in theory offering good performance, are likely to require considerable materials development because of the corrosive gases. The presence of char particles will also inhibit the performance because of adverse electrical properties. They have the additional disadvantage of requiring a large pressure vessel for a given volume of gas.

The capital costs of particulate cleanup systems have been evaluated at $150 to $200 per kW based on PFBC systems. This represents around 10% to 15% of the cost of an IGCC system.

Desulphurization

A number of different processes are under development which will offer removal efficiencies in excess of those required for NSPS standards. At present, none of these can be considered as commercial.

Calcium based systems, both in-bed and external, show considerable promise. The KRW fluid bed gasifier with calcium based sorbent appears the most likely of the processes to achieve early commercial status. Calcium based systems may also be applicable to other gasifiers by means of external beds, fixed or fluid.

More advanced processes, while in theory offering the very high capture efficiencies required for fuel cell applications, are at an early stage of development and cannot be considered as potential cleanup methods until further work is carried out at a larger scale.

There are no cost data available for desulphurization costs for IGCC systems. Data derived for fuel cell applications show that zinc ferrite may be the lowest cost and that costs range from $200 to $500 per kW.

Alkali Removal

Development of alkali cleanup methods is being hindered to some extent by lack of definition of cleanup requiremnets. Actual cleanup needs for gas turbine applications will have to be more closely defined.

A number of processes have been demonstrated at laboratory scale and show that high levels of alkali capture are thoeretically possible. Considerable development work is required before they can be considered as commercial processes.

Because of the preliminary nature of the development work in this area no estimates have been made of the costs of alkali removal systems as might be applied to IGCC. It is likely that the cost of removal of this contaminant would be in line with the cost of other contaminant removal systems.

Chloride Removal

Most work in this area has been directed at fuel cell applications. Allowable chloride levels for gas turbines still have to be defined. It is believed that chlorides from coal derived fuels is not as significant a problem as from liquid fuels.

Although chloride removal processes have been proven in concept, it will be some considerable time before they are available commercially. Preliminary cost information shows that cleanup will add significantly to the cost of electricity.

All existing commercial gasification processes utilize conventional low temperature gas cleanup, with the exception of hot cyclones used in some processes to recycle unburned char to the gasifier. Should hot gas cleanup processes be developed to commercial status, there is no reason to doubt that they would be adopted by the process developers to provide cost savings and efficiency benefits.

Developers of the KRW process will use in-bed desulphurization coupled with cyclones and ceramic filters to provide a hot gas cleanup system for its proposed Appalachian project.

Little work in hot gas cleanup has been carried out in Canada, with the exception of CANMET and work done at UBC under contract to it. This work is focussed on the development of low cost, throw-away acid gas sorbents, and preliminary evaluation of particulate removal devices.

6.2 RECOMMENDATIONS

The development of hot gas cleanup systems will become very important in the near future as the advantages of coal fueled IGCC power plants become apparent to Canadian utilities. The projected timescale for these systems to reach the commercial demonstration stage is likely to be three to five years. In the meantime, it is important that the present interest in hot gas cleanup be maintained.

The following steps are recommended to assist in this aim:

- Monitor the progress of hot gas cleanup research in the U.S. by discussions with government agencies, attendance at conferences and literature reviews. Suggested conferences include the Contractors Conferences organized annually by DOE/METC and EPRI.

- Continue to develop contacts in U.S. research programs, such as those recently established between KRW Energy Systems and CANMET. This should be done with the aim of implementing joint research programs in areas where Canadian expertise can complement U.S. work.

- As hot gas cleanup processes become more developed, carry out engineering studies to evaluate the impacts on costs and efficiencies of IGCC power plants.

- Useful research work could be carried out to identify threshold levels of alkali and chlorides in coal derived gas streams causing corrosion to gas turbine blading and other hot gas components.

PART 7

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7.1 BIBLIOGRAPHY

Numbers in brackets after entries refer to the same reference in the Gasification of Western Canadian Coal Study, Monenco Consultants Limited, January 1987.

1. Syred, N.; Biffin, M.; Dolbear, S.; Wright, M. and Sage, P.; Evolution of new concepts for compact cyclone dust separators for hot gas cleanup. Proceedings of the Gas Cleaning at High Temperatures Conference, the University of Surrey, September 1986. The Institution of Chemical Engineers, London.

2. Abrahamson, J. and Allen, R.W.K.; The efficiency of conventional return-flow cyclones at high temperatures, ibid.

3. Wheeldon, J.M.; Burnard, G.K.; Snow, G.C. and Svarovsky, L.; The performance of cyclones in the off-gas path of pressurized fluidized bed combustor, ibid.

4. Lee, S.H.D. and Myles, K.M.; Measurement of alkali vapor in PFBC flue gas and its control by a fixed bed of activated bauxite, ibid.

5. Hozumi, S, et al; Present stage of granular dust removal process development for gas cleaning of coal gasification , ibid.

6. Shaw, G.D.H.; Petrie, J.G. and Dutkiewics, R.K.; The application of moving granular panel filter to flue gas cleanup, ibid.

7. Oakey, J.E. and Reed, G.P.; The behaviour of high temperature filter materials in hot gasifier and combustor atmospheres, ibid.

8. Dellefield, R.J. and Bedick, R.C.; Evaluation of three high temperature particle control devices for coal gasification, ibid.

9. Mukherjee, D.K.; Mueller, D. and Tassicker, O.; Flue gas cleanup devices for PFBC power plants. Proceedings of Conference "Fluid Bed Combustion; is it Achieving its Promise?", The Institute of Energy, London, England, Sept 1984.

10. Rubow, L.N.; Technical and economic evaluation of ten high temperature high pressure particulate cleanup systems for PFBC, ibid.

11. Sage, P.W. and Wright, M.A.; Particulate removal developments for industrial coal-fired fluidized bed boilers, ibid.

12. Shacckleton, M.A.; Ceramic fibre filter media for high-pressure gas cleanup, ibid.

13. Morgantown Energy Technology Center; Physical gas stream cleanup; Technology Status Report No. DOE/METC-86/0239, Mar 1985.

14. Pennsylvania State University and Aerojet Energy Conversion Company; Test plan for high temperature high pressure acoustic agglomerator; Morgantown Energy Technology Center, DOE/MC/20107--T3, Aug 1985.

15. Winnick, J.; Hydrogen sulphide removal from hot gas and concentration of sulphur using electrochemistry; Annual Report Aug 1983 - Aug 1984, Georgia Inst. of Tech., Report No PB85-220614, Gas Research Institute Report No. GRI-84/0201.

16. Rugg, D.E. et al; Performance of an electrostatic precipitator at simulated pressurized fluidized-bed combustion (PFBC) conditions, Denver Research Institute contract report for Morgantown Energy Technology Center, Report No DOE/MC/16471-1887.

17. Krishnan, G.N.; Tong, G.T. and Wood, B.J.; High temperature coal gas chloride cleanup for molten carbonate fuel cell applications; prepared for the Morgantown Energy Technology Center by SRI International, Report No DOE/MC/21167--1927.

18. Baker, E.J. and Mudge, L.K.; Tar removal in a hot gas desulphurization process; topical report, prepared for Morgantown Energy Technology Center by Battelle Pacific Northwest,DOE/MC/21290--1892, Sept 1985.

19. Baker, E.J. and Mudge, L.K.; Tar removal in a hot gas desulphurization process; final report, prepared for Morgantown Energy Technology Center by Battelle Pacific Northwest, DOE/MC/21290--1892, Apr 1986.

20. Grindley, T.; Performance of zinc ferrite sorbent in simulated hot coal gas from the KRW process development unit; technical note, Morgantown Energy Technology Center, DOE/METC-85/4002.

21. Ebastec Lavalin; Study of high temperature gas cleanup; final report, DSS File No 03SQ.23440-2-9021, May 1983.

22. Oliver, E.D. and Simbeck, D.R.; Status and analysis of hot sulphur and particulate removal systems for IGCC; Proceedings of the Fourth Annual Contractor's Conference on Coal Gasification, Report No EPRI AP-4177, Aug 1985.

23. Westinghouse Electric Corporation; Gas-cleaning technology for high-temperature, high-pressure gas streams; EPRI Report No. CS-3812, Feb 1985.

24. Reijnen, K. and Van Brakel, J.; Gas cleaning at high temperatures and pressures: a review; Powder Technology, 40 (1984), 81-111 (132).

25. Ciliberti, D.F., Lippert, T.E. and Keairns, D.L.; The Development of a compact high-efficiency filter system for pressurized fluid-bed applications, the Proceedings of the Eight International Conference on Fluidized-Bed Combustion, Houston, Texas, Jul 1985, Morgantown Energy Technology Center, DOE/METC-85/6021, Vol 1 p646.

26. Kumar, K.A. and Feldman, P.L.; The use of high-temperature/high-pressure electrostatic precipitators for pressurized fluidized beds; ibid, Vol 1, p1227.

27. Grindley, T., Kim, S.S., Gorski, E.E. and Steinfeld, G.; Aspects of the design of a process development unit for high-temperature coal gas desulphurization; the Proceedings of the 5th Annual Contractors' Meeting on Contaminant Control in Hot Coal-Derived Gas Streams, Morgantown, May 1985, Vol 1, p33, DOE/METC-85/6025.

28. Jha, M.C., Hepworth, M.T. and Smith, W.E.; Enhanced sorbent durability for hot coal gas desulphurization; ibid, p76.

29. Anderson, G.L. et al; Development of a hot gas cleanup process for integrated coal gasification/molten carbonate fuel cell power plants; ibid; p87.

30. Boni, A.A., Garman, A.R., Johnson, S.A. and Simons, F.A.; Metal matter deposition and sorption of fuel-bound contaminants; ibid, p107.

31. Lyke, S.E.; Solid supported molten salt hot gas cleanup process development; ibid, p125..

32. O'Hara, J.B., Chow, J.K., Steppe, R.J., Warner, R.E. and Pham, C.Q.; Sulphur recovery from hot coal gas desulphurization processes; ibid, p137

33. Flytzani-Stephanopoulos, M., Tamhankar, S.S., Sharma, P.K. and Gavalas, G.R.; Novel sorbents for high temperature regenerative H_2S removal; ibid, p153.

34. Underkoffler, V.S., Klett, M.G. and Chen, H.T.; Systems/economic studies for high temperature desulphurization processes; ibid, p195.

35. Baker, E.G. and Mudge, L.K.; Tar removal in hot gas desulphurization process; ibid, p206.

36. Faeser, R.J. and Reethof, G.; Development of acoustic agglomerator; ibid, p235.

37. Chang, R. and Lips, H.; Ceramic fabric material testing; ibid, p256.

38. Rinard, G.A., Rugg, D.E., Durham, M.D. and Armstrong, J.A.; High temperature high pressure electrostatic precipitator characteristics; ibid, p270.

39. Wilson, K.B.; Granular bed filter evaluation in a pressurized fluid bed system; ibid, p283.

40. Kumar, K.S. and Feldman, P.L.; Sub-pilot scale high temperature high pressure ESP testing at NYU facility; ibid, p294.

41. Rubow, L.N. and Zaharchuk, R.; Results of technical and economic evaluations of ten high temperature high pressure particulate cleanup systems for PFBC; ibid, p304.

42. Ciliberti, D.F., and Lippert, T.E.; The performance evaluation of a compact high-efficiency filter on a bench-scale coal gasifier; ibid, p317.

43. Durham, M.D., Rugg, D.E., Armstrong, J.A. and Rinard, G.A.; Performance evaluation of an electrostatic precipitator on a bench-scale coal gasifier; ibid, p331.

44. Sawyer, J., Lips, H. and Chang, R.; Performance evaluation of a fabric bag filter on a bench-scale coal gasifier; ibid, p344.

45. Wendt, J.O.L. and Peterson, T.W.; Fixation of alkali and trace metals in high temperature co-current entrained flow gasifiers and combustors; ibid, p405.

46. Krishnan, G.N., Wood, B.J., Tong, G.T. and Quinlan, M.A.; High temperature coal gas chloride cleanup for MCFC applications; ibid, p448.

47. Bachovchin, D.M. and Alvin, M.A.; High temperature alkali removal by emathlite; ibid, p529.

48. Lee, S.H.D., Henry, R.F. and Myles, K.M.; Control of alkali vapours by a granular-bed sorber; Proceedings of the 4th Annual Contractors' Meeting on Contaminant Control in Hot Coal-Derived Gas Streams, Morgantown, Report DOE/MC/20035-1702, 1984, p28.

49. Jain, R.C., et al; The A.P.T. dry plate scrubber for particulate collection at high temperature and pressure; ibid, p80.

50. Feldman, P.L. and Kumar, K.S.; High-temperature, high-pressure electrostatic precipitation, current status; ibid, p102.

51. Rinard, G.A.; Rugg, D.E., and Durham, M.D.; Parametric evaluation of electrostatic precipitation for hot gas cleanup; ibid, p112.

52. Ciliberti, D.F.; Hot gas cleaning using ceramic cross-flow filters; ibid, p121.

53. Razgaitis, R. et al; Low turbulence, high-efficiency cyclone separators; ibid, p145.

54. Rubow, L.N. and Zaharchuk, R.; Technical and economic evaluation of ten high-temperature high-pressure particulate cleanup systems for PFBC; ibid, p201.

55. Case, G.D. et al; Evaluation of particulate collection devices developed for pressurized fluidized-bed combustion as applied to coal gasification process; ibid, p215, (137).

56. Grindley, T. and Steinfeld, G.; Testing of zinc ferrite hydrogen sulphide absorbent in a gasifier sidestream; ibid, p314.

57. Lyke, S.E.; Sulphide and chloride control with solid supported molten salt at high temperature and pressure; ibid, p337.

58. Anderson, G.L., Berry, F.O. and Gross, M.N.;Development of the mixed metal oxide process for the high temperature fuel gas desulphurization and a ceramic-supported molten alkali carbonate sorbent for high temperature HCl removal; ibid, p358,(138).

59. Flytzani-Stephanopoulos, M., Gavalas, G.R. and Tamhankar, S.S.; Novel sorbents for high temperature regenerative H_2S removal; ibid, p383.

60. Moore, W.E.; Overview of DOE/Fossil Energy's gas stream contaminant control program; Proceedings of the 3rd Annual Contractors' Meeting on Contaminant Control in Hot Coal-Derived Gas Streams, Washington, Pa, Report DE84-000216, Dec 1983, p3.

61. Jalan, V., Desai, M., Brooks, C. and Waterhouse, R.; Metal/metal oxides as high temperature desulphurization sorbents; ibid, p87.

62. Ham, D., Gelb, A., Lord, G. and Simons, G; Hot-gas chloride cleanup for molten carbonate fuel cells; ibid, p121.

63. Grindley, T. and Steinfeld G.; Zinc ferrite hydrogen sulphide absorbent; ibid, p145.

64. Lyke, S.E. and Sealock, L.J.; Development of a hot gas cleanup system for integrated coal gasification/molten carbonate fuel cell power plants; ibid, p173.

65. Guillory, J.L.; High-temperature moving bed granular filter development at Combustion Power Company; ibid, p245.

66. Christensen, D.; Electrostatic granular bed filter development program; ibid, p271.

67. Jain, R.C., et al; The A.P.T. dry plate srcubber for particulate collection at high temperature and pressure; ibid, p281.

68. Christensen, D., Giles, W. and Palmer, P.; Electrocyclone development program; ibid, p299.

69. Mulik, P.R., Alvin, M.A. and Bachovchin, D.M.; High-temperature removal of alkali vapors in hot-gas cleaning systems; ibid, p311.

70. Lee, S.H.D., Myles, K.M. and Jonke, A.A.; Control of alkali vapours by a granular-bed sorber; ibid, p347.

71. Kumar, K.S.; Testing and evaluation of ESP at Curtiss-Wright; ibid, p387.

72. Ciliberti, D.F.; Smeltzer, E.E. and Keairns, D.L.; Hot gas cleanup using porous ceramic cross flow filters; ibid, p409.

73. Chang, R., Sawyer, J., Kuby, M. and Shackleton, M.; Dust filtration using ceramic fiber filter media - a state-of-the-art summary; ibid, p425.

74. Linhardt, H.D.; Design and development of a high temperature particle separator for particle control in coal gasification plants; ibid, p437.

75. Haldipur, G.B., Cherish, P., Lewandowski, D.A. and Pavel, J,; Hot gas cleanup using the KRW gasifier; the Proceedings of the Fifth Annual EPRI Contractor's Conference on Coal Gasification, EPRI Report No AP-4680, Jul 1986, p11-1.

76. Corman, J.C. and Horner, M.W.; Hot gas cleanup for a moving bed gasifier; ibid, p14-1.

77. Simbeck, D.R. and Biasca, F.E.; Comparison of alternative fuel gas sulphur removal and recovery processes; ibid, p15-1.

78. Lippert, T.E. and Ciliberti, D.F.; Ceramic filter elements for high-pressure high-temperature gases; EPRI Report No CS-4382, Jan 86.

79. Lippert, T.E. and Ciliberti, D.F.; Gas-cleaning technology for high-temperature, high-pressure gas streams - 1984 Annual Report; EPRI Report No. CS-4859, Oct 1986.

80. Chang, R. and Kuby, W.; Hot-gas filtration for pressurized fluidized-bed combustion; EPRI REport No CS-3427, Mar 1984.

81. Science Applications, Inc.; Coal gas desulphurization at high temperatures; prepared for the DOE Office of Fossil Energy, Report No DOE/MC/16545-1666, DE85 003382, Oct 1984.

82. Westinghouse Electric Corporation; Testing and verification of granular filters for removal of particulate and filters; DOE, Morgantown Energy Technology Centre, Report No DOE/ET/17093-1741 (DE85 007168), Apr 1984.

83. Riepe, Th. and Wiggers, H.; Pilot tests of electrostatic precipitators at high pressures and temperatures; Proceedings of the Gas Cleaning at High Temperatures Conference, the University of Surrey, September 1986. The Institution of Chemical Engineers, London, pp297-313.

84. Tassicker, O.J.; High temperature-pressure electrostatic precipitator for electric power generation technologies: An overview of the status; ibid, pp331-349.

85. Makansi, J,; Particulate control: optimizing precipitators and fabric filters for today's powerplants; Power, Dec 1986.

86. Reed, G.P.; Filtration of high temperature fuel gases from a fluidised bed gasifier; Filtration and Separation, March/April 1985, pp106-109.

87. Grindley, T. and Steinfeld, G.; Desulphurization of hot gas by zinc ferrite; Acid and Sour Gas Treating Processes, S.A. Newman, Editor, Gulf Publishing Company, 1985, pp 419-465.

88. Jalan, V.; High-temperature desulphurization of coal gases; ibid, pp 466-496.

89. Protasio, S.F. and St. Pierre, G.R.; The use of metals and metal oxides for sulphur capture; the Proceedings of the First International Conference on Processing and Utilization of High Sulphur Coals, Oct 1985, Columbus, Ohio, edited by Y.A. Attia, pp 467-484.

90. Anand, A.K.; Private communication on General Electric Gas turbine fuel gas standards; February 1987.

91. US Department of Energy, Hot gas cleanup for electric power generating systems; Morgantown Energy Technology Center, DOE/METC-86/6038 (DE86006607), May 1986.

92. US Department of Energy, Gas stream cleanup; Morgantown Energy Technology Center, DOE/METC-86/0228 (DE86001032), April 1985.

93. US Department of Energy, Coal gasification: technology status report; Morgantown Energy Technology Center, DOE/METC-86/0242 (DE86006624), August 1986.

94. Moore, W.E.; Gas stream cleanup program review; the Proceedings of the Sixth Annual Contractors Meeting on Contaminant Control in Coal-Derived Gas Streams, edited by K.E. Markel and D.C. Cicero, Morgantown, W. Va, June 1986, DOE/METC-86/6042 (DE86001088), p1.

95. Bachovchin, D.M. and Alvin, M.A.; Simultaneous high temperature removal of alkali and particulates in a pressurized gasification system; ibid, p15.

96. Klinzing, G.E. and Blachere, J.R.; Use of solid collectors for control of emissions; ibid, p24.

97. Krishnan, G.N., Wood, B.J., Korens, N. and Anderson, G.L.; High temperature coal gas cleanup for molten carbonate fuel cell applications; ibid, p48.

98. Lee, S.H.D and Myles, K.M.; Measurement of alkali vapours in PFBC flue gas and their removal with a fixed granular-bed sorber; ibid, p58.

99. Newby, R.A.; Laboratory evaluation of high-temperature sulphur removal sorbents for direct coal-fired turbines; ibid, p78.

100. Chang, R., Sawyer, J.W. and Lips, H.I.; Performance evaluation of fabric bag filters on a bench-scale coal gasifier; ibid, p88.

101. Ciliberti, D.F., Lippert, T.E. and Meyer, J.H.; Performance evaluation of a ceramic cross flow filter on a bench-scale coal gasifier; ibid, p98.

102. Rinard, G., Rugg, D., Durham, M. and Armstrong, J.; Performance evaluation of an electrostatic precipitator on a bench-scale coal gasifier; ibid, p113.

103. Paul, D., Razgaitis, R., Jordan, H. and Faulkner, L.; Low turbulence/high efficiency cyclone separators; ibid, p123.

104. Rudnicki, M.I., Faeser, R. and Reethof, G.; Development of acoustic agglomerator; ibid, p134.

105. Ciliberti, D.F., Lippert, T.E., Smeltzer, E. and Meyer, J.H.; Performance evaluation of a cross flow filter on a subpilot-scale pressurized fluid bed coal combustor; ibid, p145.

106. Wilson, K.B., Wilson, C., Cooper, J. and Placer, F.; Performance evaluation of a screenless (counter-current) granular bed filter on a subpilot-scale PFBC; ibid, p154.

107. Kumar, K.S. and Feldman, P.L.; Sub-pilot scale high-temperature high pressure precipitator testing at NYU facility; ibid, p165.

108. Grindley, T. and Jain, S.C.; Analysis of fuel gas cleanup for molten carbonate fuel cells: The effect of temperature and pressure on the regeneration of zinc ferrite desulphurization sorbents; ibid, p190.

109. Lamoreaux, R.H., Brittain, R.D. and Hildenbrand, D.L.; Solid phase boundaries in coal gas desulphurization by zinc ferrite; ibid, p213.

110. Harrison, D.P., Ranade, P.V., Focht, G.D. and Sa, L.N.; Structural changes in metal oxide hot coal gas desulphurization sorbents; ibid, p221.

111. Jha, M.C., Hepworth, M.T., Smith, W.E., Doane, R.E. and Baltich, L.K.; Enhanced sorbent durability for hot coal-gas desulphurization; ibid, p231.

112. Anderson, G.L., Berry, F.O. and Shah, R.; Development of a hot gas cleanup system; ibid, p244.

113. Flytzani-Stephanopoulos, M., Jothimurugesan, K., Gavalas, G.R. and Sharma, P.K.; Detailed studies of novel regenerable sorbents for high-temperature coal-gas desulphurization; ibid, p257.

114. Lyke, S.E., Butner, R.S. and Roberts, G.L.; Potential benefits of improved mass transfer in SSMS hot gas cleanup; ibid, p267.

115. Underkoffler, V.S., Klett, M.G., Boulay, R.B., Buchanan, T.L. and Chen, H.T.; Process systems and economic studies for high temperature desulphurization processes; ibid, p280.

116. Bajura, R.A., Craig, K.R., Regenhardt, P.A. and Koch, R.W.; Chemical cleanup systems analysis; ibid, p293.

117. Baker, E. G. and Kothari, V.P.; Catalytic tar conversion in coal gasification systems; ibid, p314.

118. Simons, G.A., Ham, D.O. and Moniz, G.; Catalytic cracking of aromatic hydrocarbons; ibid, p325.

119. First, M.W.; Gas cleaning systems for the high temperature, high pressure fluidized bed coal combustor; Journal of the Air Pollution Control Association, Volume 35, No 12, December 1985, pp1286-1296.

120. KRW Energy Systems Inc.; Private Communication; Visit to Waltz Mill Site, 24 February, 1987.

121. Furimisky, E.; Overview of CANMET's activities in gasification research; January 1987.

122. Knill, K.J.; Gasification research in Alberta; Alberta Research Council July 1986.

123. Anon.; Technology for low-calorific gasification of coal and power generation; English translation of a paper in Japanese published by the Coal Mining Research Centre, Tokyo, 1986. (145)

124. pp 47-80 of a review of R&D at the Central Research Institute of the Electric Power Industry, Japan, covering coal gasification combined cycle and molten carbonate fuel cell development, 1986. (146).

125. Waitzman, D.A.; Lee, R.G.; Nichols, D.E.; and Williamson, P.C.; The TVA ammonia from coal project: 1985 update; the Proceedings of the Conference on Coal Gasification Systems and Synthetic Fuels for Power Generation, Volume 1, EPRI report number AP-4257-SR, Dec 1985, p 10-1. (86).

126. McCarthy, C.B.; and Clark, W.N.; Integrated gasification/combined cycle (IGCC) power production: a rapidly emerging energy alternative; ibid, p6-1. (82).

127. Sueyama, T.; Tsujino, T.; and Okada, K.; Ammonia by coal gasification; ibid, p8-1.(84).

128. Horton, E.C.; and Gockenbach, K.; Chemicals from coal: a reliable and economical alternative; ibid, p7-1. (83).

129. Hartman, J.J.; Matchak,T.A.; Sipe, H.E.; and Wu, M.; Shell-based gasification-combined-cycle power plant evaluations; EPRI Report no AP-3129, June 1983.(12).

130. Fisackerly, R.H.; and Sundstrom, D.G.; The DOW syngas project - project overview and status report; The Dow Chemical Company, 1986. (134).

131. delaMora, J.A.; Grisso, J.R.; Klumpe, H.W.; Musso, A.; and Roszkowski, T.R.; Evaluation of the British Gas Corporation/Lurgi slagging gasifier in gasification-combined-cycle power generation; EPRI Report no. AP-3980, March 1985. (3).

132. Salvador, L.A.; The Appalachian project: clean power from coal; presented at the West Virginia conference on Clean Coal Technology, West Virginia University, Morgantown, June 1986. (136).

133. Watkinson, A.P.; Cheng, G.; and Quan, R.; Hot gas cleanup of gasification products; Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada, Contract Report No. OST85-00033, February, 1987.

TABLE 7-1

Hot Gas Cleanup References

Subject	Sub-Subject	References
Particulates	Evaluations and Reviews	8,10,11,13,21,22,24,50,54,55,60,73,91,119
	Cyclones	1,2,3,10,11,22,24,53,54,55,60,68,74,75,76,81,103
	Precipitators	8,10,11,13,16,24,26,38,40,43,50,51,54,55,60,71,83,84,85,102,107
	Acoustic Agglomeration	10,14,36,55,104
	Filters	5,6,7,8,9,10,12,13,22,24,25,42,52,54,55,72,73,75,78,79,101,105
	Baghouses	8,9,11,13,23,24,37,44,55,60,79,80,85,100
	Granular Bed	5,9,10,13,22,24,49,54,55,60,65,82,106
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Alkalis	Evaluations and Reviews	60,76,91,92
	Fixed Bed	4,47,48,69,70,95,98
	Additives	45,96
	Molten Salt	57,58
Sulphur	Evaluations and Reviews	21,22,34,60,88,91,92,115,116,121,122
	Metal Oxides	22,29,33,34,58,59,61,89,112,113
	Zinc Ferrite	20,22,27,28,34,56,63,75,81,87,108,109,110,111,116,120
	Iron Oxide	80,123,124
	Calcium Based	22,29,99,120
	Molten Salt Bath	31,34,57,64,114
	Regenerator Offgas	32
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Chloride	Molten Salt Bath	29,31,57,58,64,114
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Gas Turbines	Cleanup Requirements	60,90,91
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PART 8

APPENDIX

PART 8 - APPENDIX

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MEETING NOTES

Date: Monday, 23 February 1987 FILE: CPL 8316-3

Place: Morgantown Energy Technology Centre
Morgantown, W.Va.

Subject: Review of Hot Gas Cleanup Technology

Attendees:

Tom Bechtel	Director of the Office of Technology Management, METC
Jack Halow	Director of the Coal Project Management Division, METC
Dr. Madhav Ghate	Chief, Gasification Combustion Branch, METC
Kenneth Markel	Project Manager, METC
E.J. Barry	TransAlta Utilities Corporation
G.D. Bateson	TransAlta Utilities Corporation
M. McDonald	Monenco Consultants Limited

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1. Jack Halow outlined the METC organization and the scope of its activities. The coal related activities include gasification, fluid bed combustion, gas stream cleanup, fuel cells, heat engine and components. They have the bulk of the work carried out by contract with about 300 in effect at the moment.

   The fuel cells work is directed at phosphoric acid, molten carbonate and solid oxide. Heat engines includes gas turbines and diesels. They are pursuing the concept of using coal in locomotives as a gas turbine fuel. Areas of development include fuel specification and development, combustion deposits and systems configurations. Fuel preparation is handled by the Pittsburgh Energy Technology Centre (PETC). On combustion deposits, contracts are in place with Westinghouse, Allison, Solar and G.E. Solar is looking at the development of a slagging combustor. Westinghouse is exploring the use of the AVCO Everett slagging combustor for the 501 turbine.

   Fluid bed combustion includes atmospheric projects (Georgetown) and pressurized (Grimethorpe). They consider PFBC and gasification to be at about the same level of development.

2. Dr. Ghate discussed the gasification work. The technical issues are felt to be coal quality and type, materials, control systems, efficiency and integration, and operating and maintenance costs. A recent development is the work in mild gasification. The current program emphasizes small research and development projects and the adoption of novel technologies.

Their priorities in the program are:

1. gasification for IGCC
2. for added-value co-products (using mild gasification)
3. for synthesis gas
4. for fuel gas for industrial use.

A copy of the Proceedings of the 6th Contractors Conference was provided. On the KRW process, they felt that the addition of the sorbent to the bed makes removal of the ash more difficult. The external sulphator tested satisfactorily. They are now looking at in-bed desulphurization with fixed bed and entrained flow gasifiers. Texaco will carry out tests. However, they felt that fixed beds were too low in temperature and entrained too hot to achieve more than about 10-15% capture.

The mild gasification process uses pyrolysis to produce a mixture of solid, liquid and gaseous products. They feel it could provide a broader application of coal. High volatile "B" bituminous may be the most suitable feedstock.

3. Kenneth Markel reviewed the hot gas cleanup work. Applications include co-generation, coal-fired locomotives as well as PFBC and IGCC. Benefits are seen as increased efficiency, decreased complexity of equipment and hence lower costs.

Contaminants to be removed are alkalis and particulates for protection of the equipment from deposits, erosion and corrosion; and nitrogen, sulphur and arsenic for environmental reasons. Temperature is more important to chemical processes than pressure.

The program is split into chemical contaminants cleanup - sulphur, alkalis, tars and trace species - and physical cleanup - for IGCC, direct fired turbines and diesels, and PFBC.

Under particulate cleanup, they feel the most promising candidate is ceramic crossflow filters. However, the problem of the delamination is still to be overcome. The device has a high surface area/volume ratio, low pressure drop and good cleaning performance. Work is being done by Coors and Westinghouse. They plan to test this in the New York State University PFBC and the METC 42 ins. gasifier.

Agglomeration methods, using a high level sound source of 160 dB could be used in direct-fired turbines to remove particles below 10 micron. The concept is that the sound waves cause the small particles to oscillate and agglomerate by colliding. They can then be removed in a conventional cyclone. Screenless granular bed filters have shown good efficiencies in tests, but have major engineering design problems. Electrostatic precipitators are under development by Cottrell and the Denver Research Institute. The Cottrell pilot scale ESP is being applied to the Curtiss-Wright PFBC, but has experienced startup problems. METC believes that the use of cyclones alone can remove sufficient particulate to meet NSPS requirements.

4. There are two main choices for external hot desulphurization systems, zinc ferrite, which is projected to give up to 99% removal at up to 650°C, and metal oxides with 99% removal at up to 815°C. One problem is what to do with SO_2 evolved during regeneration. For the TRW process, recycle to the gasifier is a solution, as 80% of the sulphur is captured by the in-bed sorbent.

   The mixed metal oxides produce elemental sulphur as a by-product. Zinc oxide plus cobalt titanate acts as a catalyst to remove sulphur. Another solution for the SO_2 capture is to use a fast fluid bed of calcium oxide using finely ground CaO held in a matrix of carbon fibre to allow it to be fluidized. The circulating bed captures the SO_2 and a heat exchanger removes the heat generated by the reaction. This is being developed by TRW.

5. The alkali removal requirements have as yet no clear definition. Various opinions exist as to the cleanup required. The alkali source could be either in the vapour phase, in sub-micron particles from condensation or in the particulate materials. It can be controlled either by emathelite (90% capture, throw away) or using a bauxite getter (99.5%, regenerative). It is possible that alkalis may not be a problem in fixed and fluid beds due to the lower operating temperature.

6. Upcoming conferences at METC are the Gasification Contractors on June 15-19, and the Heat Engines Contractors on April 21-23.

7. A visit was made to the lab facilities. Areas covered included the fluid bed and entrained flow gasifiers, the 42-inch fixed bed gasifier, and the direct coal fired diesel engine test facility.

DMcD:awl

MEETING NOTES

Date: Tuesday, 24 February 1987 FILE: CPL 8316-3

Place: KRW, Waltz Mill, Pa.

Subject: Review of KRW Development

Attendees:		
	Harold Biesel	KRW (part-time)
	Martin Van Sickels	VP, M.W. Kellogg Company (part-time)
	Louis Salvador	VP, Commercial Development, KRW (part-time)
	John Holmgren	VP, Technology Development, KRW (part-time)
	Dale Schmidt	Manager, Development Programs, KRW
	Kevin Smith	Process Development Engineer, KRW
	D.A. Lewandowski	Process Development Engineer, KRW
	E.J. Barry	TransAlta Utilities Corporation
	G.D. Bateson	TransAlta Utilities Corporation
	M. McDonald	Monenco Consultants Limited

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1. The scope of the TAU Hot Gas Cleanup Study was outlined. KRW then presented an overview of their development program which is funded largely by METC. The aim is to demonstrate both in-bed sulphur capture and external zinc ferrite sorbent system. The test program schedule for 1986-87 was provided (copy attached - Table I & III).

2. In-bed desulphurization. A 1985-86 test matrix was given (copy attached). A range of sorbent materials, temperatures, particle sizes and injection locations have been used. Each test was typically 200 hours over 2 to 3 wks. It was found that the limestone addition reduces deposition in the 980°C cyclones. Another beneficial effect was a reduction in unburnt carbon. This was due to dilution of the carbon in the bed from 35 to 50% to 5%. The level of COS is about 10% of the H_2S level. Agglomeration is not as important to achieve high carbon burnout with sorbent injection. The inherent calcium in the ash can be expected to capture only about 10% of the sulphur. It is felt by KRW that in-bed desulphurization provides sufficient removal and that the external zinc ferrite removal is required only for applications such as fuel cells.

3. KRW would prefer that the TAU coal test be carried out at the end of tests 037-4 or 5 (end April or end May). The run will use about 450 kg/hr. of coal and a total of 22.5 tonnes (25 tons) will be required. A sample (10 kg) will be required by the end of March for TGA analysis.

4. The major factors affecting desulphurization performance are bed sorbent concentration, H_2O content in product gas, sulphur input rate and sorbent particle size. The Ca/S mole ratio is secondary and sorbent type is of minor importance. Sulphur removal test results were given and are attached. Another beneficial effect of the limestone was an-order-of magnitude reduction in ammonia in the product gas, leading to an

equivalent reduction of NO_x. Product gas concentrations downstream of the sintered metal filter were given (copy attached). They are well below GE gas turbine specifications. Fines elutriated from the gasifier are reduced by 50%.

5. External zinc ferrite test results were given. Removal of H_2S to 10 ppm levels have been demonstrated. The regeneration gas will be recycled to the gasifier for ultimate adsorption by the in-bed sorbent. A number of additional benefits also occur with the zinc ferrite. The CO is shifted to CO_2 by injected steam to produce H_2. This improves the flame stabilization although the heating value remains approximately the same. KRW will provide a gas analysis upstream and downstream of the zinc ferrite. Steam is added to assist in the COS reaction, and to control the formation of carbon and iron carbide as these depend on the atomic C, H, O ratios. The use of high moisture lignite feedstocks may reduce the steam injection requirements.

   The zinc ferrite costs $4/lb. and has a density of between 65-85 lbs/ft^3. The temperature rises from inlet to outlet due to the shift reaction and on regeneration due to oxidation. Pressure drops may be uniform after modifications are made to allow fines to flow through the screen at the base of the containment vessel. The steam/air mixture is heated to around 540°C for inlet to the regeneration cycle. The maximum sulphur loading is theoretically 35% by weight. Up to 30% has been demonstrated. Still to be determined is the performance on low levels of sulphur (<1000 ppm) and tolerance of fines over many cycles.

6. Hot fines removal. Tests with sintered metal filters was abandoned due to metallurgical problems. A "ceramet" layer was formed and the material became brittle. A high efficiency G.E. cyclone was installed and cleaned the gas to the level required by the zinc ferrite cleanup system. It is proposed to test the Westinghouse ceramic cross flow filter to meet NSPS and gas turbine specifications.

7. The Appalachian project does not require the zinc ferrite systems to meet gas turbine inlet requirements. The product gas cooler may also be replaced by direct water injection to provide the steam required for the zinc ferrite system.

8. A tour of the KRW test facilities was carried out. The PDU was undergoing extensive modifications and refitting work and will be back in service in April. Additional TGA equipment has been added to the labs to test coal types under simulated gasifier atmospheres. In addition to this, a small scale fluid bed gasifier has been set up to enable sequential gas samples be taken during the gasification of gram scale coal samples.

DMcD/awl
Attachments

Table I - PDU Accomplishments Test Matrix

Technology Area	Primary Objectives ● Secondary Objectives ○							
Test No.	**036-1**	**036-2**	**036-3**	**036-4**	**036-5**	**037-1**	**037-2**	**037-3**
Date	**12-84**	**03-85**	**07-85**	**10-85**	**05-86**	**07-86**	**10-86**	**12-86**
In-Bed Desulfurization	● Operability	● Dolo. Bal., 90% Desul	● Rate Limits	● HHV Impr., Limestone	● Contr. Phil, Limestone	○ Shallow Bed	○ Coaxial Feed	○ SO2 Recyc
Particulate Removal & Recycle		○	○ Cyc Mod	○ L-Val Mod Met Filter	○ Met Filter	○ Cyc Mod Met Filter	○ L-Val Mod Met Filter	○ GE Cyclone
External Desulfurization						● Shakedown 1st Cycle	● 2nd Cycle	● 3rd Cycle, With Fines
Sulfation & Environmental			○ •Sulfation METC/Rad	○ Sulfation				

Table III - 1987 PDU Test Matrix

Technology Area	Primary Objectives ● Secondary Objectives ○				
Test No.	037-4	037-5	037-6	037-7	037-8
Date	04-87	05-87	08-87	10-87	12-87
In-Bed Desulfurization	○ Fate SO2	○ Fate SO2	○ Mechanistic	○ Mechanistic	○ Auto Control
Particulate Removal & Recycle	○ Deposition, C-119 Recyc, Z F Fines Loss	○ Ceramic Filt, C-119 Recyc, Z F Fines Loss	○ Pri. Recycle	○ Pri. Recycle	● System
External Desulfurization	● Polish Mode, One Cycle, UCI	● Polish Mode, One Cycle, AMAX	● Five Cycle, AMAX	● Five Cycle, UCI	○ Verify
Sulfation & Environmental			○ Gas Chara	○ Gas Chara	

KRW PDU In-Bed Desulfurization

Test Matrix for KRW In-Bed Desulfurization Pilot Plant Test Program, 1985-86

Percent Sulfur:	Pgh. #8 2.3	Pgh. #8 4.5	Wyoming 2.0
Temperature			
• 1800-1900°F	X	X	X
• 1500-1600°F		X	
Pressure			
• 180 PSIG	X		
• 230 PSIG	X	X	X
Dolomite Type			
• Plum Run	X		
• Glass	X	X	X
Limestone Type			
• Greer		X	
Dolomite Size			
• 8 x 16	X		
•12 x 30	X		
•12 x 0	X		
•10 x 40	X	X	X
Limestone Size			
•12 x 30		X	
Sorbent Injection Location			
• Freeboard	X	X	X
• Above Bed	X	X	
• Coaxial	X		
Ca:S Ratio			
• 1.0 - 1.75	X	X	X
• 1.76 - 2.50	X		X
• 2.51 - 3.50	X		

BWVA4255A 011

MEETING NOTES

DATE: Wednesday, 25 February 1987 File: CPL 8316-3

PLACE: Westinghouse R&D Centre, Pittsburgh

SUBJECT: Review of Hot Gas Cleanup Technology

ATTENDEES:

Dave Ciliberti	Westinghouse
R.M. Chamberlin	Westinghouse
D.M. Bachorchin	Westinghouse
R.A. Newby	Westinghouse
E.J. Barry	TransAlta Utilities Corporation
G.D. Bateson	TransAlta Utilities Corporation
M. McDonald	Monenco

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1. Dave Ciliberti reviewed particulate cleanup methods. Inertial methods, such as cyclones, are not considered to be good enough to attain NSPS standards. Electrostatic precipitators are likely to have trouble with carbon carryover causing spark over. Barrier filters are a much better prospect.

   Bag filters of the "bat" type were good filters, but grew a deposit on the outside which would be removed when tested at the Curtiss Wright PFBC test facility. The woven cloth type using NEXTEL made of alumina ceramic material looks like a very good candidate for PFBC. In gasification service, the char prevents a good build up of a "cake" required for good filtration and leads to pin hole formation. Work in the U.K. at CRE showed some evidence of degradation of the material in reducing atmospheres.

   Rigid barrier tube filters - 'candles' - made from silicon carbide is a good absolute filter, with pressure drops in the 7-15 kPa range. Cycling tests up to 2000 cycles showed some reduction in permeability, causing an increase in pressure drop. Tests are due to be carried out at the Grimethorpe PFBC in the U.K. Mechanical design problems with flange support and tube sheets have to be resolved in tests.

   Ceramic crossflow filters are being developed by Westinghouse. This is a laminated device having high surface area for a given volume. It is virtually an absolute filter having low pressure drops and good efficiency. It has a high through velocity of up to 6.6 cms/sec. It has been tested in bench size in PFBC and also in the METC gasifier. Delamination problems have still to be corrected. A major test program is being carried out at New York University. This will have 15 filters arranged in a 5x3 system in a pressure vessel.

The sintered metal filters tested by KRW showed metallurgical failure after limited operation. Westinghouse feel that they have limited chance of success due to the effects of H_2S and temperatures around 650°C. Other types of filters include the screenless sand filters tested by METC, which are very complex, and static bed sand filters. This type, developed by Ducon and tested at KRW, performs well but does not clean out properly due to maldistribution of gas in the beds, resulting in channelling.

Overall, Westinghouse feel that the woven bag type of filter is best, giving good efficiencies, and being easy to clean.

2. Richard Newby discussed sulphur control. This applies to gasification, pyrolysis and staged combustion. It can be in-situ and external using a once-through media or a regenerative media. The waste sorbent, if discarded, requires further processing due to the pressure of sulphide which can evolve H_2S when water is added.

Westinghouse has been working on calcium based and iron based, sorbents. Pressures up to 30 atmospheres (3 MPa) and temperatures to 1200°C have been used. Research has been aimed at sulphided sorbent regenerative reactions, reactions in processing the waste materials, sorbent attrition, and sorbent and sorbent products chemical and physical characteristics.

Equipment used includes TGA using particules up to 3000 microns, giving slow reactions; fluid bed reactors, also resulting in slow reactions; dispersed particle reactors using particles sized from 1-50 microns and fast reactions; and entrained particle reactors giving fast reactions in the 1/2 sec. range.

Information gathered from this work gives reaction kinetics, plant data correlations, plant performance modelling, sorbent characterizations and selection of operating and design conditions.

The following general conclusions have been reached on sulphur control. Calcum based sorbents are promising up to 1200°C and pressures to 30 atmospheres. Under high pressures, the sulphur capture reactions rise from 850°C (as in AFBC) to 1000° - 1200°C. Iron based sorbents are good up to 700°C, but may have high attrition rates. Both in-situ and external desulphurization have applications. Sorbent regeneration is expensive and complex. For through-away sorbents, waste sorbent processing is feasible. Removal of up to 99% of the sulphur with calcium and iron based sorbents is possible, however, care is required with sorbent selection and in operation and design.

Attrition is an important mechanism in limiting the amount of sulphur capture. The extent of capture by the inherent calcium in the coal ash is influenced by operating conditions. Westinghouse suggests that KRW could get a much higher capture of sulphur by optimizing the operating conditions.

3. Gas turbine gas cleanup requirements were discussed. The limits on particulates, sulphur and alkali depend to a great extent on the plant life required. The effects of corrosion, erosion and deposits are all inter-related. However, removal of 100% of particles over 5 to 7 microns is required to prevent unacceptable erosion. The turbine inlet temperature is not as important as the metal temperatures in the hot gas path. Vanadium is a problem, but the effects of alkalis can be suppressed by the use of additives. A limit of 1 ppm alkali in the gas is expected to be required.

4. A tour of some of the lab facilities was made. Areas covered included the pressurized cross flow filter test facility, and the sorbent test lab which uses a number of thermo-gravimetric analysers to determine reaction data. An interesting test facility was a dual TGA facility to test alkali sorbents. One TGA measures the loss of mass of the alkali to the gas flow (allowing concentration to be calculated) and another measures the increase in mass of the sorbent as the alkali is adsorbed.